

THE PRACTICE CURVE

A STUDY IN THE FORMATION OF HABITS

BY

JOSEPH HERSHEY BAIR, A.M.

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE DEGREE OF DOCTOR OF PHILOSOPHY

IN THE

FACULTY OF PHILOSOPHY, COLUMBIA UNIVERSITY,

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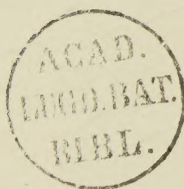
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THE PRACTICE CURVE.

INTRODUCTION.

(a) *The Problem.*

The object of the experiments here described was to investigate various aspects of association, such as the relation between the sensory and motor side of our mental life, the processes involved in the formation and modification of a habit, and, in general, to find a satisfactory physiological and psychological explanation for the phenomena of association.

The experiments were so devised as to determine the quantitative relation of the increasing permanency of an association with the succeeding practices, and also the increasing amount of interference, first when there is an alteration in the serial order of stimuli, and, secondly, when there is an alteration of particular responses to particular stimuli associated by preceding practices. Thus, by means of the interference, quantitatively determined, it was possible to venture a physiological explanation consistent with all the facts of association.

The problems of association are by no means new ones. They received consideration more than twenty centuries ago. Aristotle sought their solution. Scholars of the Middle Ages were concerned with them. The English Empiricists, Hobbes, Locke, Berkeley and Hume, went a great way toward showing how the mind retains and relates its experiences. From Aristotle down, laws of association have been stated, investigated, criticised, modified and adjusted to be consistent with our growing knowledge of psychology and physiology.

With the advent of the theory of evolution, which brought with it a wide range of problems, came again the necessity of reconsidering many problems which had received the dictum and the solution of the past. In the light of evolution all his-

tory had to be rewritten. With it came the biological sciences with renewed vigor and increased importance. Also here the genetic problems had their origin. The study of structure and function became the center of investigation. The processes involved were the chief concern of the investigators, and forms and dogmas lost much of their former sanctity. Men realized the importance of getting their knowledge from nature first hand, and Rousseau's doctrine that we must become good observers received full inspiration. Laboratories of all sorts, among them the physiological, anatomical, biological, and psychological, sprang up and became the *sanctum sanctorum* of him who would know the truth and understand the workings of the mind and the nature of things.

Locke already appreciated that the mental philosopher must have a knowledge of the bodily mechanism and for that reason studied medicine. Berkeley in his 'Essay Toward a New Theory of Vision,' pointed out the importance of understanding the physical laws involved in a perception. Hume showed that the mind connects, classifies and holds in causal relation things which in reality are not necessarily so connected. The spirit of this trio of thinkers can be seen united in the investigations of many of our modern psychologists. It has become imperative, for the psychologist, if he wishes to find solutions for some of the problems confronting him, to be well acquainted with the physiological workings of the bodily organism, and to understand, in a general way, the relations between body and mind, and between movement and thought.

It is interesting to note here the direction experimental psychology has taken within the last few years in studying and emphasizing the importance of the motor element as a factor in mental life. When laboratories for the purpose of psychological research were established experiments were directed generally toward investigating the senses and the sensory side of mental life. If movements were involved, they were studied not as produced but as perceived, much having been written on the sensations, or perception, or memory of movement, but scarcely anything on movement as an indispensable element in mental life. The tide is fully turning, and this ele-

ment is receiving due consideration. The appreciation of the importance of the motor elements is extending even beyond the laboratory, and genetic psychologists, child students, educators and philosophers alike recognize its significance, and the movements and activities of children and animals receive different interpretation. Their behavior under given conditions, their attempts to imitate others, their adjustment to new conditions through trial and error, etc., are becoming subjects of interest and discussion. And the observations thus made, and the knowledge thereby gained, tend rapidly to modify educational ideas. New curricula are everywhere advocated which involve more expression and training of the sensori-motor life, such as manual training, drawing, modeling, designing, sewing, cooking, etc., and the general tendency is to substitute '*training*' for *instruction* or *education*. The philosopher, too, is not tardy in emphasizing the importance of our motor reactions. He is becoming conscious of the fact that it is not what man sees, hears and feels that makes him what he is, but the motor-reactions which these phenomena excite.¹ Men who see and hear equally well may differ widely in their character and appreciation because they react differently under the same conditions. The present tendency is to interpret traditions, institutions and race ideals in terms of *motor adjustments*. The experiments reported in this article constitute an investigation into the motor side of association, and the results lead us to a conclusion, fully in line with the present tendency, that our associations are largely sensori-motor in character.

(b) *History of Some of the Experiments Made on Problems of Association.*

During the last century many contributions, both speculative and experimental, have been added to our knowledge of association by such thinkers and investigators as Condillac, Kant, Herbart, Mill, Hartley, Wundt, Galton and others whose work

¹ 'Psychology and Life,' Münsterberg. 'The World and Individual,' Royce. Introduction. 'The Development of English Thought,' Patten. Chapters 1, 2, 3 and 4.

bears more directly on our problem. The work of these latter we shall, therefore, briefly review, stating their problems, methods, results and conclusions.

About the first important piece of experimental work done along the line of our problem was that by Ebbinghaus in 1885.¹ He investigated the memory in terms of two of its external conditions—time and number of repetitions. He took 2300 nonsense syllables, containing each two consonants and a vowel, drawn arbitrarily into series of different length. These series were repeated until just learned ‘by heart.’ He found: (1) That the longer the series the more time spent on each syllable in just reproducing. (2) The more repetitions the less time spent on each syllable. (3) One repetition enough for a series of seven syllables. (4) The more repetitions the fewer repetitions necessary to relearn in the future. (5) Relearning on successive days reduces constantly the time for relearning. (6) Additional repetitions more than required for just learning had better be scattered than concentrated in one day. (7) If the order of the syllables in a series was changed, the time for relearning was increased. (8) The distance of impressions from one another in time and space is of very great importance—greatest liability of reproduction is correlated with direct contiguity or succession. (9) The connection of homogeneous impressions—*i. e.*, belonging to the same sense department means—a greater liability of reproduction than that of disparate. (10) The greater the difference between the group of contents and the surroundings the easier will their unification be and the greater the liability of reproduction. This law is consistent with the law of reaction, that the stronger the stimulation, within certain limits, the shorter the reaction time.

Among the several investigations which Münsterberg² has made into association, that one, the problem of which was to find whether a habit associated with a given sensory stimulus can continue automatically, while some effect of the previous and different habit associated with the same stimulus remains,

¹ ‘Ueber das Gedächtniss.’ Reviewed in *Am. Jour. of Psychol.*, 1888-9, p. 587, also in Külpe’s ‘Psychol.’ p. 178-9.

² ‘Gedächtnisstudien,’ Teil. I, Beiträge, Heft 4, 1892.

is interesting in this connection. Münsterberg denied that any laboratory method could be applied to the investigation of this problem, and claimed, therefore, that it must be studied from the actions of daily life in order to keep the attention distracted from the experiment. He had always carried his watch in the left-hand pocket and taking it out on that side had become automatic. He now practiced taking it out on the right-hand side until he did it automatically. He then returned to the old habit and found it took less time to relearn this old habit than it did to take it out on the right side automatically, and therefore concluded that some effect of the first habit remained, although the second habit had become automatic. He found that if this process of relearning successively by alternating the habits is continued, the time for relearning each habit grows less and less, following the law of the practice curve. He believes that the sensori-motor impulse does not divide like an electric current, inversely proportional to the resistance, but the whole impulse goes in one direction and that direction is determined by habit — *i. e.*, it goes the course it is accustomed to go.

Müller and Schumann¹ investigated the problem whether it will require more repetitions to relearn a nonsense syllable series if in the meantime the syllables of the series have been associated with another set of syllables. Two sets of twelve syllables each were learned in thirteen repetitions each. The relearning averaged 7.29 and 7.89 repetitions respectively. The second series was united with twelve new syllables, so that each syllable of this series entered into an association with a new syllable series. The fact that the second series was relearned almost as rapidly as the first does not deny the effect of interference. The syllables of the test series were repeated before the final relearning about twice as often as the comparison series and, therefore, there was a greater familiarity with the syllables as such. A considerable part of the work of learning a nonsense syllable series is spent in learning the individual syllables, so that in the experiment the interference effect about offset the practice effect.

¹ 'Experimentelle Beiträge zur Untersuchung des Gedächtnisses,' *Zeitschr. f. Psychol.*, Bd. VI., 2 and 3, 1893, p. 173.

Smith¹ (W. L.) investigated the interference effects of inharmonious utterances on learning nonsense syllables. He had twenty nonsense syllables in series of ten exposed for twenty seconds—immediate recall, errors noted. During the exposure he had the subject count. There were more errors with counting than normally, the relative increase of errors with counting being from 12.6 to 16.7. He also found that characters used by the deaf can be remembered better with than without hand movements.

In studying the economy of learning Jost² took two series of syllables. He repeated the first series ten times a day for three days, and the second thirty times in one day, and then relearned them. He found that distribution of repetitions yields better results than concentration. He also found that the earlier repetitions seemed more effective than the later ones.

In an experimental work by Miss Calkins³ on association, recency, frequency, vividness and primacy of connection, and their relations to one another, were studied. To a class a series of colors was presented, one at a time, through a shield for four seconds each. Each individual color was followed immediately by a numeral. A series of from five to ten colors was thus shown at periods of eight seconds each. At the close of the series the same colors in altered order were shown and the subjects asked, as each color appeared, to write down the associated numerals if any such occurred. About one-fourth of the ordinary combinations in longer series and one-third in the shorter were remembered. The repeated numeral was associated in 67.3 per cent. of the possible cases, the normal in only 24.9 per cent. Thus the frequently combined numeral was associated more than twice as often, while the unemphasized was associated slightly less often than the average. The vividly associated numerals were remembered in about one-half the series, while the normal associations with the same colors were only one-fifth the entire number. The last number was recalled in 53 per cent. of the cases. The other numerals asso-

¹ 'On Muscular Memory,' *Amer. Jour. Psychol.*, VII., 1896, p. 436.

² 'Die Assoziationsfestigkeit in ihrer Abhängigkeit von der Verteilung der Wiederholungen,' *Zeitschr. f. Psychol.*, XIV., 1897, p. 436.

³ 'Association.' *PSYCHOL. REV.*, Monograph Sup., II., 1896.

ciated with the same color only in 25 per cent. of the cases. The experiment showed the swiftly decreasing influence of recency. Primacy was a significant factor only in individual cases; comparison of recency with frequency showed that there was a definite excess of association with frequency. Frequency as a corrective influence granted a sufficient number of repetitions, it seems possible to supplement if not actually to supplant associations which have been formed through impressive or recent experience, a means of combating harmful or troublesome associations.

Another study on the relation of memory and distraction was made by Smith (W. G.).¹ He had sets of letters exposed each for ten seconds, the reagent repeating what he could remember. While memorizing the attention was variously distracted and the results compared with the normal results. Comparison showed the greatest disturbance where the mind was employed in addition during exposure, and that produced by repeating nonsense syllables was greater than that by tapping with the fingers. The relatively large number of errors of insertion and displacement in groups where distraction was greatest emphasizes the importance of the motor factor in memory, particularly in the interference of articulatory innervations involved in memorizing by the activity of the vocal mechanism.

The effect on ideas, feelings and emotions, when intensifying or inhibiting their bodily adjustments, has been studied by Breeze.² He found that mental states have an intensifying or inhibiting control over bodily adjustments and that mental states are repressed by the influence of antagonistic motor adjustments. Certain motor adjustments are very important for mental states. Many conscious states show very plainly that they are accompanied, at all times, by particular motor adjustments, and become the basis of mind-reading. In many cases the major part of the content of the mental state is that furnished by the motor adjustment. If their motor adjustments are in any way inhibited the mental states are inhibited.

¹ *Mind*, N. S., IV., 1895, p. 47.

² 'On Inhibition,' *PSYCHOLOGICAL REVIEW*, Monograph Sup., Vol. III., May, 1899.

Bergström¹ made several experimental researches on association, one of which we shall review here as bearing directly on our problem. He sorted a pack of eighty cards into ten piles of eight in a pile, each pile being composed of the same picture. In sorting a pack a second time a given card may be placed into the position it originally occupied or in one of nine other positions. In the first case we have simple practice effects, whereas if in one of the other positions, the pictures on the cards enter into associations which necessarily exclude the former associations, and we have interference. The first problem studied was the rate of decrease of interference with increasing intervals of time, between first and second sortings. An experiment consisted of two parts—first, sorting the pack of cards into piles in given positions, and secondly, sorting after a certain interval of time into piles of entirely different positions. Eight different intervals ranging from 3 to 960 seconds were used. One experiment a day for each interval was practiced at a given hour. He found by this method that the average difference between the three-second and eight-minute interval was 14.28 seconds, and between the one-minute and eight-minute interval 4.72 seconds, which shows that about two-thirds of the decrease took place in the first minute. In twenty-four hours the subject can sort the cards as rapidly as at first. This does not mean that the neural disposition has vanished. The experiment consists rather in raising the habit temporarily above the rest and noting its interference with another raised similarly above the same base of opposition. The curve of forgetting, if we put it at 30 for the three-second interval, would be 45 for the fifteen-second interval, and the decrease in the differences would be between these two points, but after about one and one-half minutes the great decrease in difference is at an end. It takes all the subjects when in practice 65 seconds to sort the first pack, and to sort the second immediately afterward about 85 seconds. This increase in time required to sort the second pack is due to false movements. The errors which the subjects were obliged to make and the consequent retardation show that a strong association had been formed.

¹ 'Relation of Interference to the Practice Effect of an Association,' *Amer. Jour. of Psychol.*, VI., p. 433.

The effect of absence of acoustic motor elements in committing visual objects to memory was investigated by Cohn,¹ also their presence as distractionary combinations. He placed twelve consonants in three rows of four each. During reading of consonants the subject either (1) pronounced the consonants, (2) suppressed all articulation, (3) pronounced other words or (4) counted. He found that judgments of recognition of order were better than those of recalling letters. Judgments of type (1) better than of type (3). The most common error was one of transposing letters from one to another column in the judgments. Practice improved the ability to recall. Recall was much affected by methods (2) and (3).

Bryan and Harter investigated the learning of the telegraphic language.² Their problem was to find the factors involved in learning telegraphy. Their method was one of observation and cross-examination of operators. They found that the student learns to distinguish most of the letters in a few hours, but after distinguishing them clearly at one time he generally finds himself confused by the back stroke and must relearn the letters many times before the difficulty is overcome. As the characters composed of four, five or six dots are made much more rapidly than the learner can count, much practice is necessary before he can be positive of the number of such dots. When a considerable speed in receiving is reached the spaces between the letters of a word become so small that one ceases to recognize them consciously, letters seem to blend together and words are recognized as a whole sound. First the letter is the unit, then the word and finally the sentence. There are distinct specialties in telegraphy so that while an operator may be competent in one department he would be a failure in another requiring no greater speed. It requires from two to two and one-half years to become an expert. The ability to send is usually greater than that to receive. Errors in the transmission of messages are comparatively few. Every operator de-

¹ 'Experimentelle Untersuchungen über die Zusammenwirkung des akustisch-motorischen und des visuellen Gedächtnisses,' *Zeitschr. f. Psychol.*, XV., 1897, p. 161.

² *PSYCHOLOGICAL REVIEW*, IV., 1897, p. 27, also VI., 1899, p. 345.

velops a distinct style of sending so that he can be recognized readily by those working with him. The motor curve is an asymptotic approach to a physiological limit. This limit was called the first plateau; it can be transcended by extraordinary effort and a second plateau can be reached. When an error is once made there is a tendency to repeat it many times.

Miss Steffins¹ studied the easiest method of memorizing 'Childe Harold.' She found stanzas to be most easily memorized by reading through as a whole until they can be repeated.

This brief summary of the work done, the methods employed and the results obtained by the several investigators of this problem of the relation of association to movement, serves to set before us the landmarks already established, and furnishes suggestions as to the best method to be employed in pursuing further researches along the same line.

METHODS AND RESULTS.

As already stated, the object of the experiments about to be described was to determine the relation between the persistence of an association and the number of times repeated, the relative persistency of connection of a particular response to a given sense impression with the number of times repeated, and finally, the relative permanency of connection with the number of repetitions, between the stimuli that follow in serial order, or the responses that follow in serial order. These relations can only be determined by measuring the interference taking place when a sense impression or a series of sense impressions to which we have previously responded with a definite movement or series of movements are now responded to by a different movement or series of movements.

The method here employed was to practice a series of stimuli, respectively, with a series of responses until these practiced reactions became automatic, or until at a given rate no more errors were made. When this was accomplished, first, the order of stimuli was changed, and the amount of interference ascer-

¹ 'Experimentelle Beiträge zur Lehre vom ökonomischen Lernen,' *Zeitschr. f. Psychol.*, XXII., 1900, p. 321.

tained either by means of the number of errors made when the time was kept constant, or by means of the increase in time it took² to run through the series when the errors were kept constant, *i. e.*, at zero; and, secondly, when this new order was practiced until again there were no more errors, when the time was kept constant, or until the rate approached the physiological limit, when the errors were kept constantly at zero, new responses were practiced to the old order of stimuli and the interference again determined in terms of the increased number of errors, or the increased time. The relative rates of adjustment and readjustment, when the order of stimuli or the order of responses to stimuli was changed, were also determined by the number of practices it took to reach zero, when the time was kept constant, or, to reach the physiological limit when the errors were kept at zero.

These experiments were made on a Blickensderfer typewriting machine.¹ To the carriage in an upright position was attached a black screen which moved with the carriage and in which was a narrow slit the width of a letter printed by the typewriter. Immediately behind this screen was a horizontal wooden cylinder two and one-half inches in diameter and the length of a page printed by the typewriter. This cylinder was held in position against the screen by a frame. It could be turned on its axis so as to bring any part of its surface in line with the slot in the screen. Around this cylinder was fastened a white paper on which were printed in six different colors, arbitrarily arranged, a series of fifty-five. This series appeared in a horizontal line on the cylinder, and every time a key was pressed on the typewriter a different color appeared in the slot, due to the movement of the slot forward with the carriage. Immediately underneath this first series (series A), was arranged in a similar horizontal manner a second series (series B) containing the same colors but in a different serial order. A third

¹ Professor Jastrow first suggested capping the keys of the typewriting machine at the New Haven meeting of the American Psychological Association in 1899-00, and in 1901 Dr. Wissler, in some experiments at Columbia, used caps, screen and color series in much the same way I did in these experiments.

series (series C), differing only in two places from series A, was placed under series B.

Underneath these three color series on the same cylinder in a similar manner to the color series were arranged three letter series, A, B and C, made up of six letters, and fifty-five in the series. Any series could be brought in line with the slot by turning the roller on which they were placed.

The typewriter contained three rows of keys. The six middle keys of the first row were covered with caps containing each one of the six colors composing the color series. The six middle keys of the second row were covered with caps containing each one of the letters of the letter series, and the third row of keys was covered with blank caps. A sheet of paper was kept in the machine, and every time a key was pressed the letter of that key was printed on the paper, and in this way the errors were easily determined.

An experiment consisted in pressing, respectively, the keys corresponding to the colors or letters as they appeared in the slot. Either the subject kept time with the beat of the metronome and the errors were scored, or he made his associations as rapidly as possible without errors and the rate was determined with a stop-watch. In the experiments represented on Plate II. the time was kept constant on the color series and the practice or adjustment curve determined by the number of errors, and in the letter series the subject was required to go as rapidly as he could without errors and the practice curve determined from the decrease in the number of seconds required in each successive practice.

The *first experiment* was made before the caps were devised for the keys. It consisted in taking seven letters on the keys, four in the first row of keys and three in the second. These seven letters were arranged in a series of fifty-five. The daily experiment consisted in running over this series three times, the first two times at the rate of one per second, keeping time with the beat of the metronome, and the third time taking the rate with a stop-watch. It took nine days' practice — *i. e.*, going over the series twenty-seven times — to get rid of the errors at this

rate. And the average number of errors in the first practice was twenty-nine.

TABLE I.

Ba.	{	Errors	{	37	20	23	11	5	3	2	2	0
				28	13	6	5	3	2	1	1	0
		Time		81	77	57	64	59	56	56	52	49
Me.	{	Errors	{	22	7	6	3	1	1	1	1	0
				11	5	2	1	2	1	4	0	0
		Time		80	64	57	55	54	53	57	50	47
Mi.	{	Errors	{	50	31	30	26	21	12	7	4	1
				41	26	26	19	14	6	3	0	0
		Time		88	81	64	59	57	58	56	55	52
Sm.	{	Errors	{	25	17	11	11	6	4	2	0	0
				21	15	6	2	3	1	1	1	0
		Time		68	65	63	61	54	49	44	42	39
Av. Errors			29	27	14	10	7	4	2.5	2	1/4	
Av. Time			79	72	63	60	56	54	53	49	47	

Table I. shows the results of experiment I. The upper two horizontal columns for each subject represent the number of errors for each day's practice, beginning at the left when the time was constant at one per second; the lower or time column beginning at the left represents the number of seconds it took from day to day when the subject did it as rapidly as possible, without any errors. The first column in black type represents the average errors for the successive practices of all the subjects and the second column the average time. This table shows that the association curve follows the regular practice curve. With practice both the number of errors and the time required to run through the series are constantly decreased until the number of errors reaches zero and the time required the physiological limit.

The *second experiment* was with the color series. It consisted in going over the series eight times each day in succession, the subject keeping time with the beat of the metronome, increasing the rate of the metronome each time, except the last, when the subject did it at the most rapid rate he was able without making mistakes. The daily practice consisted in running over the series at each of the following rates per minute: 60, 66, 72, 80, 88, 96, 104, and lastly the subject's most rapid rate.

A certain arrangement of the colored keys (arrangement A) was thus daily practiced with the color series (series A) until no more errors were made at any of the rates. Then

color series B was substituted for series A, and practiced in like manner until no more errors at the most rapid rate were made. Then the keys were interchanged and the new order (arrangement B) was practiced with series B until all errors were eliminated. Color series B was then again practiced with arrangement A until all errors were overcome, and then, finally, the order first practiced was again returned to and practiced until all errors were once more reduced.

TABLE II.

A. SERIES A—ARRANGEMENT A.						B. SERIES B—ARRANGEMENT A.					
Rate.	Ba.	Me.	Mi.	Sm.	Av.	Rate.	Ba.	Me.	Mi.	Sm.	Av.
60	12	9	20	7	12	60	0	0	0	0	0
	17	20	32	16	21	60	1	1	1	1	1
66	13	16	30	13	18	66	1	1	5	0	2
	18	21	28	25	16	66	9	9	17	2	9
72	20	18	35	18	23	72	2	1	11	1	4
	31	35	42	40	37	72	17	17	25	10	17
80	32	21	38	21	28	80	5	3	12	2	6
	50	41	60	53	51	80	27	27	35	19	27
88	37	26	43	36	33	88	4	2	22	3	8
	83	74	89	81	82	88	60	44	67	44	54
96	43	34	47	29	38	96	6	5	29	3	11
	95	92	101	97	96	96	77	68	85	61	73
104	46	41	48	26	40	104	8	9	37	7	13
	124	128	136	130	129	104	86	86	94	78	86

C. SERIES B—ARRANGEMENT B.						D. SERIES B—ARRANGEMENT A.					
Rate.	Ba.	Me.	Mi.	Sm.	Av.	Rate.	Ba.	Me.	Mi.	Sm.	Av.
60	11	1	8	2	6	60	0	0	0	0	0
	9	9	9	9	9	60	1	1	1	1	1
66	17	2	16	2	9	66	0	0	1	2	1
	17	10	25	10	15	66	2	2	9	9	5
72	14	4	17	3	10	72	1	2	8	1	3
	26	26	26	18	23	72	10	10	17	10	12
80	15	5	21	5	12	80	2	1	14	2	5
	61	36	51	36	43	80	11	18	27	11	17
88	15	8	32	7	16	88	3	2	20	3	7
	68	52	68	44	58	88	19	12	28	12	18
96	14	13	42	7	20	96	4	5	21	3	8
	85	77	77	69	77	96	29	21	37	21	27
104	18	14	46	13	23	104	5	3	23	5	9
	102	94	110	86	98	104	29	29	46	38	36

TABLE II.—*Continued.*

E. SERIES A—ARRANGEMENT A.

Rate.	Ba.	Me.	Mi.	Sm.	Av.
60	0	0	0	0	0
	1	1	1	1	1
66	0	0	2	0	$\frac{1}{2}$
	2	2	9	2	$\frac{4}{5}$
72	0	0	0	1	$\frac{1}{5}$
	3	3	3	10	$\frac{5}{6}$
80	1	0	5	0	$1\frac{1}{2}$
	11	4	11	4	$\frac{8}{9}$
88	2	4	5	1	$\frac{3}{4}$
	12	12	20	14	$\frac{14}{14}$
96	5	3	9	4	$\frac{5}{5}$
	21	13	21	13	$\frac{17}{17}$
104	9	7	13	8	$\frac{9}{9}$
	22	22	30	14	$\frac{22}{22}$

TABLE III.

A. SERIES A—ARRANGEMENT A.

No. of Exper.	Ba.	Me.	Mi.	Sm.	Av.
8	62	66	62	55	$\frac{61}{61}$
16	52	49	57	52	$\frac{53}{53}$
24	50	54	55	45	$\frac{51}{51}$
32	49	43	54	43	$\frac{47}{47}$
40	48	39	49	41	$\frac{44}{44}$
48	44	37	45	40	$\frac{42}{42}$
56	44	37	44	39	$\frac{41}{41}$
64	42	36	43	36	$\frac{39}{39}$
72	42	37	43	40	$\frac{40}{40}$
80	44	36	45	38	$\frac{41}{41}$
88	42	38	40	39	$\frac{40}{40}$
96	41	36	44	40	$\frac{40}{40}$
104	41	36	40	38	$\frac{39}{39}$
112	42	35	41	34	$\frac{38}{38}$
120	41	36	40	36	$\frac{38}{38}$
128	40	34	40	36	$\frac{37.5}{37.5}$

B. SERIES B—ARRANGEMENT A.

No. of Exper.	Ba.	Me.	Mi.	Sm.	Av.
8	45	40	44	43	$\frac{43}{43}$
16	44	36	43	39	$\frac{40.5}{40.5}$
24	44	37	43	39	$\frac{41}{41}$
32	39	38	47	40	$\frac{41}{41}$
40	40	36	42	36	$\frac{38.5}{38.5}$
48	38	37	39	35	$\frac{37}{37}$
56	38	36	40	32	$\frac{36.5}{36.5}$
64	39	40	38	35	$\frac{38}{38}$
72	40	36	37	33	$\frac{36.5}{36.5}$
80	40	36	36	34	$\frac{38}{38}$
96	36	36	36	33	$\frac{35}{35}$

C. SERIES B—ARRANGEMENT B.

No. of Exper.	Ba.	Me.	Mi.	Sm.	Av.
8	52	48	47	42	$\frac{47}{47}$
16	46	44	44	42	$\frac{44}{44}$
24	46	40	44	39	$\frac{42}{42}$
32	45	41	39	39	$\frac{41}{41}$
40	44	39	39	37	$\frac{40}{40}$
48	44	36	40	34	$\frac{38.5}{38.5}$
56	40	37	37	34	$\frac{37}{37}$
64	40	36	35	35	$\frac{36.5}{36.5}$
72	40	36	36	35	$\frac{37}{37}$
80	42	36	35	31	$\frac{36}{36}$
88	38	36	36	33	$\frac{36}{36}$
96	37	35	35	34	$\frac{35}{35}$
104	38	39	35	32	$\frac{36}{36}$
112	37	37	38	31	$\frac{36}{36}$

D. SERIES B—ARRANGEMENT A.

No. of Exper.	Ba.	Me.	Mi.	Sm.	Av.
8	36	41	39	31	$\frac{37}{37}$
16	36	36	35	30	$\frac{34.5}{34.5}$
24	36	37	35	30	$\frac{34.5}{34.5}$
32	37	35	37	32	$\frac{35}{35}$
40	35	32	34	29	$\frac{33}{33}$
48	35	31	33	29	$\frac{33.6}{33.6}$

E. SERIES A—ARRANGEMENT A.

No. of Exper.	Ba.	Me.	Mi.	Sm.	Av.
8	35	34	36	30	$\frac{34}{34}$
16	32	32	35	30	$\frac{32}{32}$
24	34	31	32	28	$\frac{31}{31}$

TABLE IV.—*Continued.*

E. SERIES A.—ARRANGEMENT A.

104	9	5	1
	<i>1.5</i>	<i>2</i>	<i>.5</i>
96	3	2	
	<i>6.5</i>	<i>1</i>	
88	1.5		
	<i>1</i>		

Tables II., III. and IV. show the results of the second experiment. In table II. the upper horizontal columns for each rate indicated in the margin, in each of the orders practiced [*i. e.*, Series A, Arrangement A, B-A, B-B, etc.], show for each individual the number of errors, and the average number of errors, in the first practice at that rate, and the columns immediately below in *italics*, show, respectively, the number of practices required to eliminate all the errors at that rate.

Table III. shows the rate at which each of the subjects could run over the series at the number of practices indicated in the margin for each of the orders, A-A, B-A, etc., practiced.

Table IV. represents the same experiment. In each of the orders, A-A, B-A, etc., the upper horizontal column at each of the rates indicated in the margin represents the average number of errors at each succeeding practice at that rate, and the column immediately below in *italics* represents respectively the mean variation of the errors, at the said rate and number of practices, for all the subjects. The first line represents the mean curve and the second line at each of the rates found in the margin the mean variation of that curve—*i. e.*, see Plate I.

The *third experiment* is represented by Tables V. and VI. Seven students, four of whom served in the first two experiments, acted as subjects. Each subject practiced at one rate only, one subject for each rate, and the old subjects for the higher rates. The latter series, thus far practiced by none of the subjects, were used, only the color series having been practiced by the old subjects. An experiment consisted in going over the letter series each day five times at his respective rate by each subject. Each of the three new subjects also practiced over the color series five times each day in succession as rapidly as possible without making any errors. First letter series A and key arrangement A were practiced together until all errors were eliminated, then the order was changed and practiced until no more errors. The following orders were practiced each until no more errors:

1. Letter series A.—Key arrangement A.
2. " " A.— " " B.
3. " " B.— " " B.

TABLE V.

A.						
Ca.	Da.	Mi.	Go.	Me.	Ba.	Sm.
60	66	72	80	88	96	104
12	25	38	36	38	44	46
<i>16</i>	<i>21</i>	<i>36</i>	<i>55</i>	<i>52</i>	<i>59</i>	<i>66</i>
4	15	22	24	29	32	34
5	17	25	41	23	29	37
0	1	5	7	9	10	13
B.						
-3	-6	-14	-3	2	-4	1
-1	-4	-3	-10	2	-2	-3
-2	-4	-1	5	-5	2	2
-0	-3	-4	-2	-2	-4	-6
1	-3	-3	3	3	1	1
1	0	1	-6	1	2	-4
-3	-1	-3	1	-1	1	2
C.						
2	-2	-5	2	-6	-3	-5
-2	-3	-3	-5	-3	3	2
-1	-1	1	2	1	-6	-2
-2	1	-3	-3	-4	1	1
	-3	-1	1	2	-5	-2
	-1	-2	1	-3	-2	-1
	-2	1	-2	1	2	-3

Table V. shows the result of this experiment. In section A the numbers below each name represent the rate at which each practiced. The perpendicular column underneath each name represents the results of that subject. The first horizontal column below the rate shows the number of errors made by each subject at his rate in the first experiment, and the second column immediately below in italics, the number of practices required to eliminate the errors at that rate. The next two columns show, respectively, the number of errors in the first experiment and the number of practices required to eliminate them when the keys were changed, and the last two columns proceeding downward when the letter series was changed. Section B of Table V. shows the rate of decrease in the number of errors for each subject with each practice. The columns are to be read vertically below each name at that rate. The upper figures represent the decrease in errors of the second practice over the first, if the figures are preceded by a minus sign, if not preceded by the sign the figures represent an increase of errors. Likewise the second figure represents a decrease in number of errors of the third practice over the second, etc. Section C shows similarly the decrease in the number of errors with the successive practices when the keys were changed.

In the *fourth experiment* on the typewriter three new subjects practiced daily five times in succession the color series for seven successive days. Then the caps were interchanged and the new order practiced in a similar manner five days. Then the caps were placed in the order first practiced and the time ascertained in which the subject could run through the series.

TABLE VI.

	Go.	Da.	Ca.	Av.		Go.	Da.	Ca.	Av.		Go.	Da.	Ca.	Av.
A.	62	79	82	74	A.	46	43	49	46	B.	53	51	58	54
	59	75	68	67		47	42	47	45		50	50	56	52
	58	60	65	61		46	44	46	45		51	51	54	52
	58	57	73	63		47	41	48	45		52	50	52	51
	53	69	58	57		47	42	35	45		49	50	53	48
	52	52	57	54		43	45	35	44		47	46	50	48
	49	59	58	55		42	42	44	43		44	48	50	47
	50	49	54	51		44	41	45	43		55	50	48	48
	51	50	56	52		46	40	42	43		43	49	49	47
	51	47	60	53		48	37	41	41		44	46	50	47
	49	49	62	53		43	40	44	42		42	44	51	46
	49	51	53	51		41	41	62	41		42	41	46	43
	50	48	52	50		44	39	40	41		40	40	44	41
	50	43	50	48		42	36	41	40		41	38	42	40
	50	44	51	48		40	38	42	40		40	38	44	41
	47	46	51	48	B.	58	60	70	63		39	39	42	40
	46	44	49	48		56	55	59	57	C.	56	54	49	53
	47	46	49	47		56	54	60	57					
	46	44	51	44		54	54	59	56					

Table VI. shows the results of the three new subjects who practiced at their own speed on the color series five times each day. The perpendicular columns under each name represent the time in seconds for the successive practices. Section A represents the first arrangement of colors and keys, section B shows the results of the keys changed, and C of the series changed. The last column in italics shows the average curve. The results of this experiment are shown by Plate II., 1 and 2.

Table VII., page 24, represents the *fifth experiment* on the typewriter. Two short-letter series of twenty each were made up of six different letters. The third row on the typewriter, containing six keys covered with blank caps, was used. Immediately in front of this row in a stationary position was placed a strip of white cardboard upon which were printed the six letters of this series at distances apart, so that each letter was directly in front of one of the blank keys. On the opposite side of this card was placed the same group of letters, but in different

ferent letters or figures each (no two letters or figures being alike in any two series). Each series consisted of a group of fifty-five. These twenty series were placed on the roller in a similar manner to those already described. On twenty strips of cardboard were printed the respective letters or figures of the twenty series, so that when they were placed in position in front of the blank keys one letter was directly in front of each key. Three new subjects were procured, and one of the old subjects, Sm. was the fourth. The experiment shows a decided practice effect for all the subjects, although no two of the twenty series were alike. It cannot be argued that the practice effect was due to getting adjusted to the machine, or to getting adjusted to a common element in all these series, for Sm., who had many previous practices in the other experiments, showed almost as much practice effect as the new subjects.

TABLE VIII.

Wr.	Fa.	Js.	Sm.	Av.	Mv.	Wr.	Fa.	Js.	Sm.	Av.	Mv.
62	95	71.5	65	<i>74</i>	<i>11</i>	59	85	62	60	<i>66.5</i>	<i>9</i>
61	93	68	65	<i>72</i>	<i>8</i>	59	85	70	57	<i>68</i>	<i>10</i>
62	88	66	63	<i>70</i>	<i>10</i>	58	87	65	56	<i>66.5</i>	<i>12.5</i>
60	91	63	64	<i>70</i>	<i>11</i>	57	84	64	58	<i>66</i>	<i>9</i>
60	87	63	61	<i>68</i>	<i>12</i>	55	86	61	58	<i>65</i>	<i>10.5</i>
55	88	66	60	<i>67</i>	<i>10.5</i>	54	87	61	57	<i>65</i>	<i>11</i>
56	91	64	60	<i>68</i>	<i>7</i>	52	85	57	56	<i>62.5</i>	<i>11</i>
53	90	61	62	<i>66.5</i>	<i>12</i>	52	87	60	55	<i>63.5</i>	<i>11.5</i>
57	85	67	65	<i>66</i>	<i>45</i>	53	84	62	58	<i>64</i>	<i>10</i>
60	88	58	62	<i>67</i>	<i>10.5</i>	52	84	58	56	<i>62.5</i>	<i>10.5</i>

Table VIII. shows the results of the sixth experiment. The figures in the vertical columns show the number of seconds it took to run over the successive series. The column in italics shows the average time it took all the subjects, and the last column the mean variation. These series were not gone over by any two of the subjects in the same order. This was done to be sure that all the series, if not alike difficult, would be distributed by chance.

The *seventh and last experiment* with the typewriter also represents one continuous practice. Eight series of letters of twenty in a series, with the same letters in two series, were made and put on the roller behind the screen. The first series contained but two letters, arbitrarily arranged, the second series contained the same letters, but differently arranged. These two series we shall refer to as series D and D'. The next two series were made up of three letters different from those of the first two series, and similarly arranged in serial order. These are series N and

N'. Likewise the fifth and sixth series and the seventh and eighth were arranged respectively from four and five different letters. These are series M and M', and series O and O'. The blank keys in the third row of the machine were used. On eight strips of cardboard were put the letters of the respective series at distances to suit the keys. These letters were arranged in two different orders for each series. These orders I shall refer to respectively as arrangements D and D', N and N', M and M', and O and O' to correspond with the series.

An experiment consisted in practicing through the series in the following orders, repeating each order ten times.

Two-letter series.	{	1. Series D	Arrangement D
		2. " D'	" D
		3. " D'	" D'
Three-letter series.	{	1. " N	" N
		2. " N'	" N
		3. " N'	" N'
Four-letter series.	{	1. " M	" M
		2. " M'	" M
		3. " M'	" M'
Five-letter series.	{	1. " O	" O
		2. " O'	" O
		3. " O'	" O'

A short rest was taken at the middle of each of the orders practiced.

TABLE IX.

ERROR.						
Rate.	Ba.	Me.	Mi.	Sm.	Av.	Mv.
66	17	22	27	18	21	3.5
72	26	28	33	29	29	2
80	35	37	41	35	37	2
88	36	36	46	38	39	3.5
96	37	40	45	42	41	2.5
104	39	43	50	40	43	3.5
Time:	69	66	71	68	69	15

Table IX. shows the results of a test experiment on the typewriter, made for the purpose of filling in the curves on Plate I. (dotted lines). Different series of fifty-five made up of six different letters, one series for each rate. The experiment was made in the same manner as experiment V., but with the beat of the metronome instead of taking the subject's most rapid time. The practice at each different rate was on a different series. The averages for all the subjects at each rate were the numbers used in completing the curves in Plate I. These values are not the same as we would have gotten [judging from the results of experiment V.] had we made the very first experiment at the rate of one or other of the curves, instead of beginning at the lowest rate and getting partly adjusted until we get to the more rapid rates.

Section I. shows the decrease in the number of seconds required to run over the series with the increasing number of practices. Section II. shows the interference and rate of readjustment when the series are changed, and Section III. the interference when the letters on the keys are interchanged. This table shows that the interference is greatest when the greatest number of reactions are involved, and greater when the keys than when the series are changed.

TABLE X.

2				3				4				5				
	Mi.	Me.	Sm.	Av.	Mi.	Me.	Sm.	Av.	Mi.	Me.	Sm.	Av.	Mi.	Me.	Sm.	Av.
I.	21	20	19	20	27	24	22	24	26	27	26	26	32	31	33	31
	19	19	17	18	25	20	20	22	26	22	24	24	32	24	25	27
	21	19	17	19	23	19	18	20	24	21	24	23	29	23	26	26
	19	18	16	18	23	20	19	21	23	22	20	22	27	24	24	25
	22	18	16	19	24	18	18	20	22	22	21	22	26	22	22	23
	20	20	17	19	21	18	18	19	20	20	20	20	26	20	20	22
	20	18	16	18	22	16	15	18	20	21	20	20	24	21	20	22
	19	18	15	17	20	17	17	18	20	19	18	19	25	20	21	22
	17	17	16	17	18	17	15	17	19	20	18	19	22	19	18	20
	17	17	15	16	17	16	14	16	19	20	17	19	20	19	18	19
II.	22	24	23	23	24	21	23	23	23	23	24	23	25	23	24	24
	19	22	20	20	23	20	22	22	23	22	21	22	26	21	24	24
	18	21	18	19	21	19	20	20	22	20	22	21	24	22	21	22
	19	21	18	19	20	20	20	20	20	21	11	20	20	21	20	20
	21	19	18	19	20	20	19	20	19	19	18	19	21	21	20	21
	21	20	16	19	21	19	20	20	19	20	18	19	20	20	19	20
	17	16	17	17	20	16	18	18	18	21	16	18	19	19	19	19
	16	17	16	17	18	18	17	18	19	19	17	18	20	19	20	20
	17	14	15	15	17	16	15	16	18	18	16	17	18	20	18	19
	15	14	13	14	18	16	16	17	18	19	17	18	18	19	17	18
III.	22	24	24	24	28	28	26	27	29	31	27	29	30	32	28	30
	21	20	22	20	25	24	21	23	25	27	28	27	30	29	25	28
	20	20	19	20	25	23	23	24	23	24	26	24	27	28	26	27
	21	19	18	19	24	22	20	22	24	23	22	23	24	25	24	24
	19	18	18	18	20	21	20	20	20	23	21	21	25	23	20	23
	20	17	16	18	21	20	18	20	21	22	21	21	22	24	21	22
	18	18	18	18	19	21	18	19	20	21	19	20	23	21	21	22
	19	16	17	17	20	18	17	19	21	18	19	19	22	23	19	21
	17	15	15	15	19	19	16	18	19	19	17	18	19	20	20	20
	16	15	14	15	19	17	17	18	20	18	18	18	20	20	19	20

Table X. shows the results of three subjects and their average. The perpendicular columns below each name show the results of that subject in the 2, 3, 4 and 5 letter series. In Section I., when first order was practiced, in II., when the series were changed, and, III., when the keys were changed.

Other experiments besides those with the typewriter, relating to the motor side of association, were made. These I shall now describe.

The first of these consisted in taking daily records, for twenty days, by means of a stop-watch, of the time required to repeat the alphabet from memory. Each day's experiment was as follows: First, the alphabet was repeated as rapidly as possible forward; secondly, the letter *n* was intercepted between each of the letters; thirdly, the alphabet was repeated as rapidly as possible backward; and lastly, the alphabet was repeated backward intercepting *n* between each of the letters. At the end of twenty practices in each order the subject repeated the alphabet, first, forward, intercepting, instead of *n*, the letter *x* repeating three times; secondly, intercepting *r* and repeating three times; then lastly, repeating backward, and in like manner intercepting *x* and *r* and repeating three times.

TABLE XI.

ABC	Me.	2.7	2.6	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.5	2.4	2.4	2.2	2.3	2.5	2.4	1.7	
	Ba.	3.5	3.4	3.2	2.9	2.7	2.6	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.4	2.5	2.5	2.5	
	Mi.	2.5	2.7	2.5	2.7	2.5	2.5	2.5	2.7	2.7	2.6	2.5	2.4	2.5	2.5	2.4	2.4	2.5	
	Av.	2.9	2.9	2.8	2.8	2.6	2.6	2.6	2.6	2.7	2.6	2.5	2.4	2.4	2.4	2.5	2.4	2.2	
A _n B _n C _n	Me.	25	14	11	10	10	11	10	9	10	7	8	7	7	6.5	6.7	7	7.5	
	Ba.	27	18	13	13	11	12	12	8	8	7.5	7	6.5	6	5.7	6	6.2	6.5	
	Mi.	20	14	13	10	9	8.5	11	8.5	8	8	5.5	6	6	5.5	5.5	6	6	
	Av.	24	15	12	11	10	11	11	8.5	8.5	7.5	6	6.5	6.3	5.9	6.1	6.4	6.8	
ZYX	Me.	35	27	18	19	17	15	16	16	20	14	25	11	15	16	10	10	9	
	Ba.	32	25	16	14	12	9	10	7.5	6	7	5	7.5	4.5	3.5	2.7	2.5	2.5	
	Mi.	27	21	17	18	15	13	16	10	12	14	9.5	9.5	10	7	5.5	5	4	
	Av.	32	24	17	17	15	12	14	11.5	13	12	9	9.5	10	9	6	6	5	
Z _N Y _N X _N	Me.	43	35	27	20	19	20	25	19	24	16	18	7.5	16	14	16	16	14	
	Ba.	56	44	35	24	16	9.5	9.5	13	10	8.5	8.5	8	7	10	10	8	8	
	Mi.	35	33	34	24	18	17	15	14	13	17	14	10	9	13	10	8	9	
	Av.	45	37	32	23	18	18	17	15	16	14	14	9	9	12	11	11	10	
A _x B _x C _x	Me.	8	7	7	7														
	Ba.	9	9	8	7														
	Mi.	16	13	12	13														
						A _r B _r C _r	12	11	12	8	7								
							12	14	9	8	7								
							18	14	10	11	10								
												Z _x Y _x X _x	25	26	20	18			
														27	19	17	15		
														21	19	18	19		

Table XI. shows the results in number of seconds required for these experiments. The upper three horizontal columns in each of the sections show the results of three subjects whose names appear in the margin, and the fourth column the average. These averages are plotted in Plate II., 3. The table shows the regular practice curve. The fifth part of the table shows the same as experiment V., Table VIII., that one kind of practice helps us in another kind.

The second general experiment consisted in a test of the improvement of rate of movement with practice. It was also to show the effect of interference when some modification of the figure practiced was made. On a sheet of paper on which was printed a figure 10 cm. square, containing one hundred squares 1 cm. square, making ten rows of ten squares each, the subject drew curves as rapidly as possible in each row of squares. These curves were composed of loops, some turned up and some down, one loop in each square. Each sheet of paper contained ten curves. The time it required to fill up one sheet of curves was determined by a stop-watch. Each day's practice consisted in filling up six sheets. On the last sheet the curve was slightly modified in two places by interchanging two loops that were turned in opposite directions.

TABLE XII.

Ba.	Me.	Mi.	Ba.	Me.	Mi.	Ba.	Me.	Ba.	Me.
61	69	92	42	55	43	35	45	34	38
51	63	65	41	57	44	35	47	33	35
45	60	52	44	62	48	33	42	33	36
51	58	55	41	53	46	35	40	35	34
44	59	51	37	50	42	33	42	32	34
49	70	56	38	50	44	36	44	32	34
41	56	44	36	46	43	34	43		
39	52	43	37	44	43	35	40		
40	57	39	62	51	47	33	40		

Table XII. shows the results of this experiment. The perpendicular columns show the results of each subject whose name is printed above. The figures in italics show the interference when figure is modified after five practices. The time it took the subject to write each curve was also determined as well as possible by the attendant. These results are not represented in the table because they are not absolutely accurate, but they show that in each paper the time required to produce the curve decreased very rapidly at first, less rapidly respectively in the second and third, and in the fifth practice each curve began to take, on the average, longer, due to fatigue. In the sixth sheet when the curve was modified the first curve took considerably longer than any of the succeeding. The adjustment to the new curve was very rapid. If we compare the time it took to produce the practiced curve the last time with that of the modified curve the first time, the second is more than twice the first. This is due to pauses made while the curve is being produced.

The next experiment was to get a curve for the rate of perception. On a sheet of paper were printed 508 letters in thirteen lines containing one hundred *a*'s arbitrarily arranged. The test consisted in seeing how long, from day to day, it would take the subject to mark all the *a*'s. Each day's practice consisted in marking from five to seven papers, sometimes marking the last few backwards.

TABLE XIII.

Ba.	Me.	Mi.	Ba.	Me.	Mi.	Ba.	Me.	Mi.	Ba.	Me.	Mi.
100	68	122	72	58	90	70	55	73	58		65
83	62	92	71	59	88	73	55	71	54		90
85	61	82	71	52	71	67	53	69	62		
77	56	86	66	55	68	65	49	72	60		
70	54	81	70	49	62	71	56	70	57		
71	62	81	67	61	62	68	49	71	90		
69	61	74	66	65	66	62	48	73	57		
70	55	79	62	58	82	66	77	68	88		
71	53	77	65	52	79	59	74	62			
71	54	77	84	47	71	60	70	65			
76	64	93	72	55	68	61	62	94			

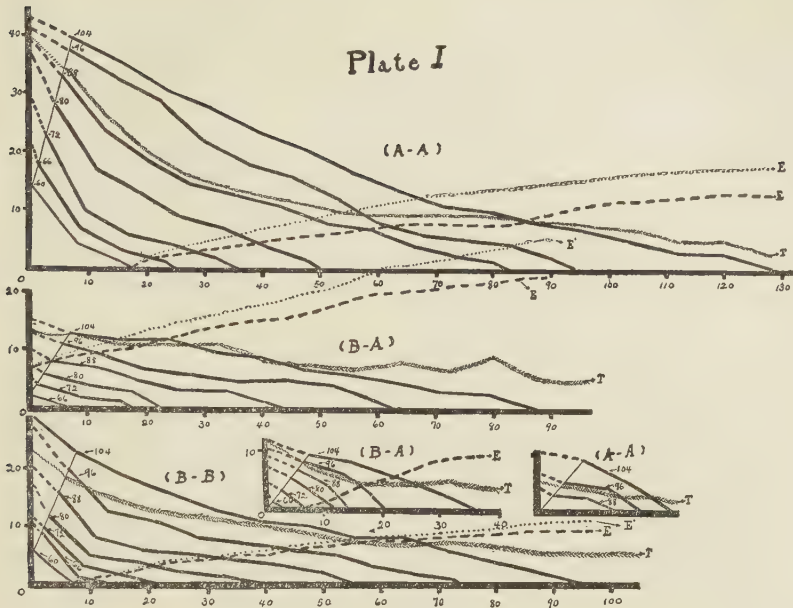
Table XIII. shows the results of the A experiment. The figures in italics show the increase in time required when they were marked backward, contrary to the accustomed order. The letters in black show the interference when only every other α was marked.

The next test is one to get the curve for the improvement of accuracy of movement with practice. The test was to determine how many shot out of sixty the subject could put at a distance of two feet into a wine glass.

TABLE XIV.

Ba.	Me.	Mi.	Sm.	<i>Av.</i>	Ba.	Me.	Mi.	Sm.	<i>Av.</i>
28	37	43	45	38	13	32	24	27	24
24	35	41	41	35	11	26	24	26	22
17	34	30	36	29	9	27	25	26	22
20	41	29	39	32	7	32	21	20	20
12	33	28	34	27	6	26	20	22	19
20	28	26	30	26	6	20	19	28	18
17	22	23	30	23	5	22	20	27	18
15	24	24	34	24	4	36	20	20	20
13	28	25	37	24	5	24	17	19	16
17	32	22	31	25	4	23	17	18	15

Table XIV. shows the results of the successive daily practices in throwing shots into a cup. The figures in the perpendicular columns show how many out of sixty in each practice the subject, whose name heads the column, got into the cup. One practice was made each day, and the last column, in italics, shows the average number of shots put in each of the successive practices.



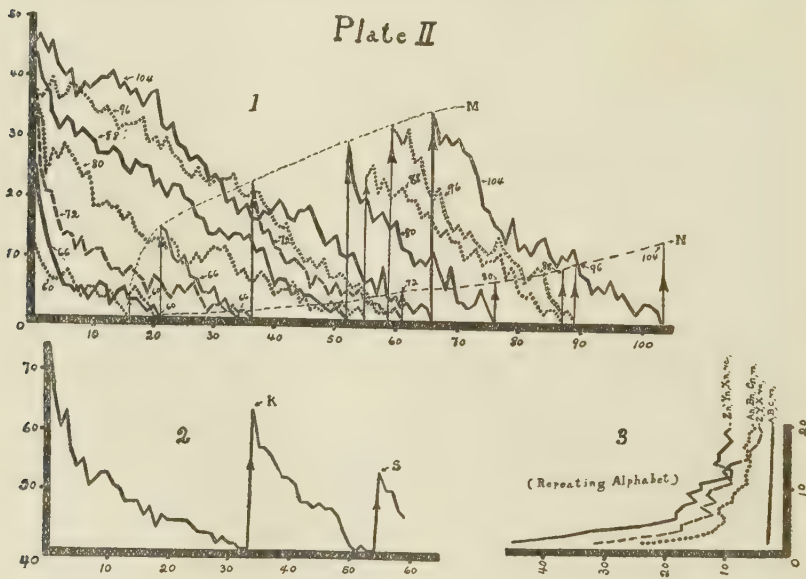
DESCRIPTION OF PLATE I.

In the curves on this plate the ordinates show the number of mistakes in the error curves, represented by the smooth lines, and the rate, represented by the feathered line. The zero abscissa line is the line of no mistakes in the error curves and the thirty seconds line in the rate curve. Since the least time in which any of the subjects could run through the series without an error was thirty seconds, this time was considered as the physiological limit, and any rate slower than thirty seconds was represented by so many points above the zero abscissa. In this way the time curve and the error curves were made closely comparable. The abscissas represent the numbers of practices, each practice representing a point in advance of the previous practice on the abscissa. The seven smooth curves represent the mean error curves for all the subjects at the seven rates practiced. The lower curve represents the curve for the slower rate, *i. e.*, 60 associations per minute and each of the succeeding curves respectively a more rapid time, the upper curve representing the most rapid rate, *i. e.*, 104 associations per minute. The daily practices consisted in running through the series successively eight times from the slowest to the most rapid rate, and concluding by taking the subject's time, which is represented by the feathered curve. The errors at each rate for each day's practices were marked on the coordinate paper in the following manner: The number of errors at the first (slowest) rate of one day's practices was marked at their respective place one point to the right of the last rate of the previous day's practices. Each succeeding rate, in order, was marked one place to the right of the preceding at its respective place on the ordinate, so as to represent the number of errors of that rate. This makes the error points at each rate eight places apart on the abscissa. These points

of each rate were connected by straight lines to form the curve for each rate. The dash lines at the beginning of each curve represent the probable form of the curves, determined by test experiments if the first practice had been at the rate of that curve, instead of getting partly adjusted by preliminary experiments at lower rates.

The curves of (*A-A*) represent the first series of practices, which were continued until all the errors were eliminated at all the rates. (*B-A*) shows the interference and the number of practices at each of the rates, practicing through in the same order of rates when the serial order of stimuli was changed, (*B-B*) when the keys were changed, (*B-A*) when the keys were changed back again to their former positions and (*A-A*) when the original order was again referred to.

The dash line *E* represents the interference which took place at the different rates when the order was changed, and the dotted line *E'* the interference which would have taken place if, when the series or keys were changed, the first practice had been at the rate of each of the curves instead of, as usual, going through the series of rates and thus getting partly adjusted to the new arrangement before the first practice at, *e. g.*, 96 or 104 per minute. The interference lines *E* and *E'* are formed by connecting the points representing the number of errors which occurred or would have occurred at each rate when the order was changed, these error points being placed on the ordinates respectively passing through the points where the curves at each rate reached zero.



DESCRIPTION OF PLATE II.

The curves in Plate II., first figure, represent the results in errors obtained from seven subjects, each practiced at one of the rates throughout. The subject practiced five times a day at his rate until he made no more errors, then the

keys were changed and the experiment was continued until the errors were again eliminated, when the color series was changed and the interference at that rate noted. This experiment succeeded that represented by Plate I., and four of the subjects, those practicing at the 72, 88, 96, and 104 rates, had served in the first experiment, on a different series. Their curves show that they learned more rapidly than the other new subjects, their previous practices helping them to get adjusted more rapidly.

The light dash line *M* shows the curve of interference when the keys were changed and the heavy dash line *N* the interference when the series were changed, these interference curves being formed by connecting the error points of the first practice at each of the rates when a change in the order is made.

The second figure of this plate represents the time curve. This curve is the mean time curve of the three new subjects practicing through a series of fifty-five, five times each day for seven days, when they did it at an average of forty seconds. Then the keys were changed and the practice was continued until the average was again forty seconds, which required five days' practice, then the series was changed and the increase in time noted. In all these experiments the subject made the usual daily practices just before and about two minutes after the change of series. According to Bergström's results the interference would not have been so great if the interference practices had been made the day after the last practice of the old order.

The third figure represents the mean curves of four subjects in the alphabet experiments; the ordinates represent the time in seconds.

TABLE XV.

B.	C.	S.	F.	E.	S.	C.	E.	G.	M.	D.
5 yr.	4 yr.	3 yr.	2 yr.	2 yr.	2 yr.	2 yr.	2 yr.	1 yr.	2 yr.	2 yr.
2.3	2.5	4.2	4.1	5.3	3.5	5.1	4	6.2	5.7	6
2	2.2	1.8	4.2	4.1	2.2	3.2	2.8	4.3	4.7	4
2.1	1.7	1.7	2.6	3.2	1.5	2.7	1.7	4.1	3.6	3.1
I	1.2	1.2	2	2.9	1.3	1.6	1.3	2.5	3	3.2
I	I	1.2	2.7		1.2	1.1	1.2	2.7	1.5	1.9
	I	1.5	2.4		1.1	1.3	1.3	1.9	1.1	1.6
		I	1.9		I	I	I	1.3	I	1.2
		I	1.5		I	I	I	I	I	I

Table XV. shows the results of the ten children tested. The perpendicular columns headed by name and age of the child whose results that column represents show the influence of practice on discrimination. The figures, the successive practices being represented downward in the column, show the average number of trials each child made with each block in the successive trials. If the numbers be multiplied by ten we have the total number of trials in each experiment required by each child to get all the blocks in. The board was kept cleared of blocks, so that the conditions as far as possible were kept constant throughout the experiment. This experiment shows that the child learns to discriminate slowly. Likes and differences are not always immediately perceived, but that accuracy of discrimination also follows the law of the practice curves. It is evident from these results that the child learns to discriminate in about the same way as the animal.¹

¹ 'Animal Intelligence,' Thorndike, PSYCHOLOGICAL REVIEW, Monograph Supplement.

The last experiment was on children of from two to five years of age. The purpose of it was to determine the rate of improvement of discrimination with practice. The method used to make this test was to see how many trials were necessary for the child to put ten blocks of various shapes into their respective holes in a board. The blocks and their holes were all about the same size, and no block could be put into any but its own hole. Each block had a handle to it so that the child would always get the right side of the block on the board.

Other experiments to test the relation between thought and movement, such as saying as rapidly as possible 1, 1, 1, . . . while thinking a, b, c, . . . , putting oneself in a certain bodily attitude to see whether some reminiscence usually accompanying that attitude would come up, trying to think upper then lower *do* without adjusting the vocal organs, etc., were made, but these experiments, since the results cannot be tabulated, will be discussed in the next section of this article.

Besides the experiments so far described I have made another series of tests similar to those on the typewriter but with cards. These experiments were partly a duplication of those made by Bergström in 1892.¹ Since his results did not seem to compare with mine, I thought it advisable to duplicate some of them in order to try to find out the reason for the conflicting results.

The cards I used were similar to his, having ten pictures and eight cards of each picture. I used only one interval, the one, minute interval between the first and second dealings. In the second dealing the cards were placed in a different order and were dealt in different positions. I found considerable interference but not nearly so much as Bergström. I then tried to find how much of the interference is probably due to suggestion. A number of subjects were tested who did not know Bergström's results nor the object of this experiment. They were asked to determine introspectively how much easier it goes the second time than the first. The results were as follows:

1. 19 subjects influenced by suggestion: *first dealing*, 89^6 *M. V.* ± 9 ; *second dealing*, 87^5 *M. V.* ± 13 .

¹ 'Experiments upon Physiological Memory by Means of the Interference of Association,' *American Journal of Psychology*, Vol. V., pp. 356-372.

2. 21 subjects familiar with Bergström's results: *first dealing*, $79^5 M. V. \pm 9.8$; *second dealing*, $87 M. V. \pm 10.7$.

1 and 2. 40 total number of subjects: *first dealing*, $84.2 M. V. \pm 9^5$; *second dealing*, $87.4 M. V. \pm 11.8$.

In 1 the second dealing averaged two seconds less than the first.

In 2, when the conditions were similar to those under which his experiments were made, the second averaged 7.5 seconds more than the first dealing.

Bergström's results show ¹ that in the first dealing the average time required was 84.15 seconds and the second 96.34 seconds, making the second 12.19 seconds longer than the first.

I found slight interference on the typewriter also when practicing one series once and then changing the keys and practicing a different serial order.

The question came up whether the interference becomes greater with the number of practices—*i. e.*, does a habit which has been made permanent with many practices offer more resistance to displacement by a different habit than one formed by only one or a few practices? To test this the experiments reported in Table XVI. were made. From the eighty cards used in the former experiment forty-two were taken with six different pictures and seven of each picture. These cards were dealt as rapidly as possible in one order and immediately afterward, at one minute interval, in a different order and the interference noted in length of time the second required over the first dealing. Then on the typewriter the subject ran as rapidly as possible over a series of six different colors forty-two in the series reacting on six different keys, and then changing the keys and the serial order of colors and repeating after one minute interval. Then the cards were again dealt in the same order and position, on the table, ten times with intervening intervals of one minute, and then changing back to the second order and repeating once, and then doing the same thing on the typewriter. The results show (Table XVI.) that the difference in time required, between one dealing and another requiring antagonistic reactions, becomes slightly greater

¹ See Table IV., page 362, *op. cit.*

with the number of practices of one order before the other is taken up, but this increasing difference is due to the increase in speed gained in the practice of the first order, and not to interference. The results show that it takes less time to make the associations in the second order after practicing the first order ten times than it does after practicing it only once.

TABLE XVI.

Name.	Time in seconds required for first practice.		Time in seconds required for dif- ferent order im- mediately after- ward.		Time required in 10th practice of the same order.		Time required when change is made after 10 practices of the same order.	
	Type- writer.	Cards.	Type- writer.	Cards.	Type- writer.	Cards.	Type- writer.	Cards.
Ba.	38 ⁵	38 ⁵	41	39 ⁵	34 ⁵	30 ⁵	39	39
	39 ⁵	40						
Sm.	35	33	36	37 ⁵	29	26	34	33
	34	34 ⁵						
Ju.	47	39 ⁵	53	48	40	34 ⁵	48	44
	46	41						
Mi.	42	35	49 ⁵	38 ⁵	32	27	42	34
	38	35 ⁵						
Hm.	42	37	50 ⁵	41	38	26	42 ⁵	36
	43 ⁵	34						
Js.	45	33 ⁵	53	37 ⁵	30	25	46	35
	47	34 ⁵						
Ts.	46	45	47	52	37	37	46	44
	44	42						
Fn.		34		38 ⁵		23		34
		35						
Hn.	51	40 ⁵	58 ⁵	41	34	30	50 ⁵	39
	49 ⁵	36 ⁵						
Av.	43	37 ⁵	48.1	41.1	34. ³	28 ⁵	43 ⁵	36 ⁵
Av. Var.	± 4.3 ± 3		± 5.4 ± 3.5		± 3.4 ± 4.1		± 4.3 ± 3.5	

Table XVI. shows the time required to make 42 association reactions on the typewriter and in dealing the cards. The first two perpendicular columns of figures show the time in seconds required to go through, for the first time, the series of 42 reactions on six keys of the typewriter, or to deal out 42 cards into six different positions. The second two columns show the time required immediately after when the keys were interchanged and the cards put into different positions. The third two columns show the number of seconds required to make the tenth practice in the same order. The last two columns show the time required to run through the series in a new order immediately after ten practices in the same order have been made.

I have continued this experiment for twenty, thirty and forty practices in one order before the other order was practiced, and found that the more practice in one order one makes the less time it takes to run over a different order. The table shows the results of this experiment.

TABLE XVII.

Typew. Cards.	Typew. Cards.	Typew. Cards.
First practice.		Immed. after in different order.
38 ⁵ 38 ⁵		41 39 ⁵
First practice.	Time required in 10th practice of same order.	Time required after changing to new order after 10 practices.
39 ⁵ 40	34 ⁵ 30 ⁵	39 39
First practice.	Time required in 20th practice of same order.	Time required after changing to new order after 20 practices.
37 41	29 25	36 37
First practice.	Time required for 30th practice of same order.	Time required after changing to new order after 30 practices.
39 37	24 23	34 32
First practice.	Time required for 30th practice of same order.	Time required after changing to new order after 30 practices.
36 38	21 20	32 ⁵ 31 ⁵

I also made the same experiment with one subject on the full series on the typewriter (Series A and B, etc., as described on pages 15-16). The following table shows the results:

TABLE XVIII.

		(Subject Bn.)
First practice.		Immediately after in different order of keys. 77
68 ⁵		
2 days afterward, same order.	Time required in 10th practice of same order.	Immediately after 10th practice when order of keys was changed. 73 ⁵
69	65	
5 days afterward, same order.	Time required in 20th practice of same order.	Immediately after 20th practice when order of keys was changed. 68 ⁵
63	58 ⁵	
2 days afterward, series B.	Time required in 30th practice of same order.	Immediately after 30th practice, key arrangement C. 66
67	54	
4 days later, key arrangem't C.	Time required in 30th practice of same order.	Immediately after 40th practice, key arrangement D. 64
65 ⁵	50	

The same experiment was also made using the same series with a different subject, when the rate was kept constant at 104 with the beat of the metronome, and the number of errors were kept account of, with the following result .

TABLE XIX.

First practice.		(Subject Ba.) Immediately afterward in different order of keys.
39		47
3 days afterward, same order.	Same order. Time required in 10th practice.	Immediately after 10th practice, order of keys changed.
39	31	45
2 days afterward, series B.	Time required in 20th practice of same order, series B.	After 20th practice, when keys were changed to series C.
40	26	40
3 days later, series C.	Time required in 30th practice of C.	After 30 practices of series C, when changed to series D.
38	22	38

I made also another experiment with the cards comparable to the fifth experiment on the typewriter, page 23, the results of which are shown by Table VIII. and the mean curve of which results is shown on Plate III. (4), *i. e.*, I used the eighty cards and sorted them twenty times, each time having the cards arranged in different order in the deck and also on the table upon which they were dealt; each kind of card in each sorting was put into a different position. Two subjects were tested in this experiment, and curve 3, Plate III., shows the results.

Introspections were taken in all these experiments, but these will be given account of in our discussion and interpretation of results.

SUMMARY OF RESULTS.

The results of the experiments described can be summed up in the few following statements:

1. By practicing a particular reaction, or series of reactions, to a certain stimulus, or series of stimuli, until these responses become automatic, and then associating the same response, or series of responses, with a different stimulus, or series of stimuli, or a different order of responses with the same set of stimuli until the new order becomes automatic, and then again returning to the first order, going from one order to the other every time the order practiced becomes automatic, the time becomes continually less for the subsequent adjustments until, finally, after a sufficient number of alternating adjustment practices, either

order can be responded automatically, one needing but voluntarily to start the response impulse in one direction or the other, and the whole series of responses proceed as though that were the only order ever acquired. These results show that the neural disposition of an old habit does not vanish when a new one is formed which excludes the old. Some residue remains in the cells once associated, so that with a very few practices a definite connection can again be established.

2. In practicing a series of responses with a series of stimuli until they became automatic, when the time is kept constant by means of a metronome, the decrease in the number of errors follows the law of the practice curve.

3. The greater the number of possible reactions the slower the rate of adjustment and the later the time at which no errors will be made.

4. There are less errors made and it takes fewer practices to eliminate them at the slower rates than at the faster.

5. When the errors are kept constant, *i. e.*, at zero, the time required from day to day is constantly reduced by practice until the physiological limit is reached, or at least approached.

6. If after the responses have been repeated many times to a certain serial order of stimuli, and then either the order of stimuli, the order of stimuli to responses, or both, are changed, there will be a considerable rise in the practice curve, of errors when the time is kept constant, or of increased time when the errors are kept constant. The rise in the practice curve being larger when the particular responses to particular stimuli (sensori-motor connections) are altered, than when a change in the serial order of stimuli (physiologically speaking, motor-motor or sensori-sensory connections) is made. The rise is still greater when both the sensori-motor, and sensori-sensory, motor-motor connections are changed.

In none of these three cases, however, when, in one order, a number of practices sufficient to approach the proficiency limit were made, did the curve rise as high, when the change was made, as it started in the first practice.

7. There may be such a thing as interference when a change is made upon a few practices, but the rise in the practice curve

seems to be due to the learning of the new order, and not to interference.¹

DISCUSSION AND INTERPRETATION OF RESULTS.

Tables I., II., III. and IV., being a summary of the results of the first two experiments, show, first, the rate at which a series of stimuli can be reacted to by a series of responses, and how this rate can be constantly increased by successive practices; second, that any rate faster than the rate at which the subject can just make all the reactions correctly results in a certain number of errors, and that the more rapid the rate with the same amount of practice, the greater will be the number of errors, until a certain limit is reached beyond which the laws of chance operate, and that the number of errors at any given rate is constantly decreased with continued practice until all the errors at that rate are eliminated. We have found by trial that the number of errors at any rate above one hundred and four per minute for the average subject without previous practice, is entirely dependent on chance. One hundred and four per minute was therefore taken as the upper limit for speed of association in these experiments.

The average number of errors at this rate for the four subjects tested, in the first practice, was 40, and it took these four subjects an average of 129 practices to eliminate all the errors. It took on an average 62 seconds, after seven practices, at the subject's own rate, without making any errors, to run through the series, and on the one hundred and twenty-eighth practice the average was only 37.5 seconds at the subject's own rate without errors.

When the color series was changed, *i. e.*, color series B substituted for A, there were 13 errors, and it took 86 practices to eliminate the errors at the 104 per minute rate. In the eighth practice of this order at the subject's own rate, it took an average of 43 seconds to complete the series. At the end of this read-

¹ I wish here to express my obligation to those who have given me their assistance in this research, Professors Cattell, Farrand and Thorndike, for their suggestions, and Messrs. Miner and Messenger for their daily services as subjects, and to all others who acted in a similar capacity.

justment practice, *i. e.*, when the subject could again run over the series at the 104 rate (the 86th practice) without making errors, it took an average of 35 seconds, at the subject's own time without an error, to make the series.

When now the keys were interchanged, *i. e.*, when arrangement B was substituted for arrangement A, there were 23 errors at the 104 per minute rate, and it took 98 practices until at this, the most rapid rate, there were no more errors. See Tables II. and IV., pp. 18-20.

When color series A was again substituted for B it took 37 seconds in the eighth practice after the change to run through the series at the subject's own rate without errors, and in the forty-eighth practice, when the readjustment was completed, it took 33.5 seconds at the subject's own rate. In the seventh practice of this order, at the 104 rate, there were 9 errors, and it took 36 practices to eliminate them.

When now again the combination as first practiced — *i. e.*, series A, arrangement A — was resorted to in the seventh practice, there was an average of 9 errors at the 104 per minute rate, and it required 22 practices to eliminate the errors at this rate. The time it required to run through this series on the eighth practice was 34 seconds, and on the twenty-fourth practice 31 seconds.

The order followed in all these series of practices was at the following rates in order: 60, 66, 72, 80, 88, 96 and 104 per minute, there being always six practices at the slower rates before the most rapid rate, 104 per second, was reached, thus gaining considerable adjustment at these rates before the higher rates of speed were practiced. But for matters of comparison the results are just as good as though we had the full practice curve at each rate, because our figures represent all the curves compared with the same amount of adjustment practice.

In this discussion we shall use only one rate, the 104 rate, for comparison of the interference which takes place when the order of stimuli to responses, or the serial order of stimuli or responses is changed. By referring to the tables of the results, it may be seen that any of the rates, if compared, will show about the same proportion of interference with number of prac-

tices and proportional number of practices required to eliminate the errors at that rate. Plate I. shows graphically the results of this experiment, and the relation between the 'interference' and the number of practices required to become readjusted.

The third experiment, the results of which are represented by Tables V. and VI., and by Plate II., shows, like the experiment just discussed, the number of errors at each rate per minute and the number of practices at that rate per minute required to eliminate the errors. It likewise shows the interference when the order practiced was changed and the number of practices required to gain readjustment. The advantage of this experiment over the previous is that it shows the complete practice curve at each rate and the real 'interference' at that rate when the order is changed, and in this way the 'interferences' at the different rates may be compared with each other. Instead of each subject practicing daily through the series of rates, as in the previous experiment, he practiced at one rate only (one subject for each rate). The results show, like the first, that the more rapid the rate the more errors, the more practices required to eliminate them, and the greater the 'interference' when the order is changed.

At the 104 rate, 46 errors were made in the first practice and it took 66 practices to overcome all the errors at this rate, and when the arrangement of keys was altered, after perfect adjustment was brought about through practice, at this 104 rate there were 34 errors and it took 37 practices to eliminate them. When now the series was changed 13 errors were made. At all the rates in this experiment the relations were somewhat similar, but not so much so as in the experiment immediately before this. Those practicing the higher rates became adjusted comparatively more rapidly than those practicing at the lower rates. This is due, probably, to the fact that the four subjects who practiced at the higher rates had acted as subjects in the previous experiment, and it is possible that this enabled them to get adjusted more rapidly than the naïve subjects. If this is true it shows that training in one function gives us at least power to learn in another similar function more rapidly than without that training. It shows that training in one situation creates capacity to receive

training in another similar to it; also (it might be argued) that understanding one situation better prepares one to grasp and comprehend other situations.

The results of these experiments show that every time the color series or the keys of an order practiced are changed there is 'interference,' and it requires a certain number of practices proportionate to the rate to make readjustment, and thus quantitative relations are determined. The number of errors at the same rate per minute and the time required to eliminate them are in no case as great as when at first practiced. The tables further show that neither the 'interference' nor the adjustment practices required are as great when the order of stimuli is changed as when there is an alteration between responses and stimuli.

Münsterberg¹ was not wrong when he concluded that it takes less time to relearn a habit each time we return to it, *e. g.*, if we had once learned to react to a stimulus A , or a series of stimuli $A, A_1, A_2, \dots, A_n$, respectively by act M , or a series of acts $M, M_1, M_2, \dots, M_n$; and in the meantime we reacted voluntarily to the same stimulus A or series of stimuli $A, A_1, \dots$, by act N , or series of acts $N, N_1, N_2, \dots, N_n$ until these responses became automatic, each time we return to act M , or series of acts $M, M_1, \dots$ it takes less time to relearn to respond by that act automatically. And if we keep on returning from one response, or series of responses, to another, for several times, both become automatic, and one can react equally well by either response. One needs but *start* the impulse in the direction of one of the responses M or N , and the act ensues as easily and automatically as though no other act had ever before been associated with the stimulus. When I had learned, *e. g.*, to respond automatically to series A on the typewriter by both the key arrangements A and B, I could, after a few alternating practices, run over either arrangement equally well at the 104 rate, the interference having become less and less with the alternating practices, following somewhat the practice curve, until no more interference was experienced.

In Plate I. the time curves T are plotted with the same coordinates as the error curves, except that because the physiological

¹ See review of his work on page 8.

limit for speed was found to be about 30 seconds to run through the series, and, in order to make the time and error curves comparable, 30 was regarded as the zero point for the time curve, and the number of seconds, less 30, it took in the successive time experiments was plotted in the same way as the errors. It can be seen empirically that the two are not strictly comparable. However, the error curves, as well as the time curves, when compared with each other for the different rates per minute, show that the slower the rate the more rapid is the decrease in the number of errors with the succeeding practices. In the slower rates the decrease in the number of errors is at first quite rapid and then more slow, while in the more rapid rates the decrease is more gradual throughout. The time curve also drops rather rapidly at first, and then more gradually. In the 129th practice when the average subject could run through the color series without an error at the 104 rate, the average time at which he could run over the series at his own rate was 37.5 seconds. This shows that at his own most rapid rate it took 5.5 seconds longer than when keeping time with the metronome. It is difficult to understand the reason for this, but an analogous case is that of an army on the march. Every one knows that it is easier to march to time. An almost exhausted army will start up with new vigor when the drummer begins. Another explanation might be that the beating of the metronome serves to keep one excited and thus helps to hold the attention to the experiment, whereas without this, when the attention wavers much time is lost. Table X. shows that the greater the number of different reactions in a number of series of the same length, the longer it will take to go over the series, the more rapid the adjustment and the greater the 'interference' when the order of reaction is interchanged. This is probably due to the impossibility of shifting the attention rapidly enough. Any motor operation which requires much shifting of the attention offers much resistance to speed both at first and when antagonistic reactions are to be learned. The other general experiments summed up in Tables VIII. to XV. will receive attention in our more general discussion.

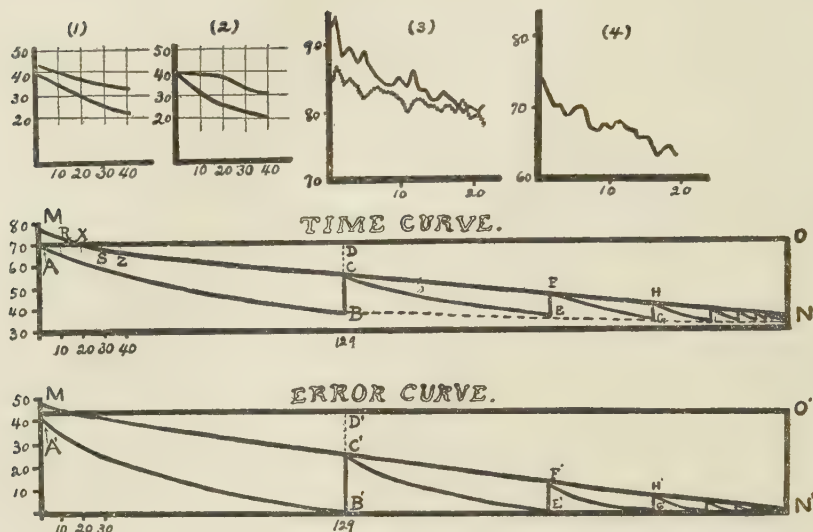
Coming now to the subject of *Interference*, it is difficult to decide; but if our interpretation is correct real interference

plays a very small part in our mental life. Of course, it depends largely on what we mean by interference. If (referring to our diagram 'Time Curve,' Plate III.) we call BC , the increased time required when the order of responses is interchanged, interference we shall not take issue with those who argue for it; but if we mean by interference such an increase in time upon a change of the order of responses that the point C of BC falls above the line AO representing the time of the first practice in the first order, then from our results it can be argued as doubtful whether there is any interference whatever. Our results show, however, that when an order of reactions is made once, or only a few times, there is actual interference when an antagonistic order is attempted; but that this interference decreases proportionally to the number of practices until at between twenty or thirty practices of this order the interference is all gone and a continued practice has an actual practice effect on an antagonistic order. How much practice effect can be procured by an indefinite number of practices in an antagonistic order our results do not show definitely, but one is justified in assuming that it is considerable. Our results show that the practice effect on arrangement B by practicing arrangement A 129 times is CD , which is considerable. Without any practice with arrangement A, it would have taken at first to run through the same series on key arrangement B, $BC + CD$ seconds, which is the same time it took to complete the series in the first practice on arrangement A. If our results justify us in drawing any conclusions, we might say that special practice or training gives general ability, or that learning to do one thing gives us capacity for learning to do other things, and the same thing in different ways.

Bergström argues that interference is a fundamental fact of the nervous system, and that an old habit always resists displacement. "It is easier to act in the old way, but it is not evident that we cannot learn a new way, if we try, *as easily* as we learned the old one. * * * In the small field of the present experiments it will appear, however, that in spite of every effort a very decided interference takes place when we attempt to associate a new reaction with an old stimulus."¹

¹*Amer. Jour. of Psychology*, Vol. V., p. 356.

Plate III.



DESCRIPTION OF PLATE III.

Curves (1) and (2) on this plate show graphically the results tabulated in Table XVII., page 37. Curve (3) shows graphically the individual results of two subjects who dealt the cards twenty times in succession, with one-minute intervals between the sortings and a five-minutes' rest in the middle of the experiment. Each time the cards were arranged in different order and placed in different positions on the table.

Curve (4) shows graphically the results of a comparison experiment to (3) on the typewriter. See Table VIII. The curve represents the average, or mean curve.

The 'time curve' shows schematically the results of the time experiments. It is based on Table III. and Plate I., the *flattened* curves. The ordinates, like in Plates I. and II., represent in the time curves the time it took to run through the series, and in the error curves the number of errors at a constant rate, and the abscissas represent the number of practices. In the time curve 30 is taken as the base line because 30 seconds is about the most rapid rate any subject acquired in the practices, and is therefore considered as the physiological limit. Curve *AB* represents the first practice curve, *CE* the second practice curve when the keys were interchanged, *FG* the practice curve when the keys were again changed back to the first order. And the succeeding curves, *HI*, etc., represent the curves changing back and forth alternately from one order to the other until either became automatic. *BC* and *EF*, etc., show the *interference* (?) which takes place when one order is substituted for another practiced. *CD* shows the amount of practice we get in arrangement of stops *B* by practicing arrangement *A* 129 times, etc. The curve *MN* represents the practice effect one order practiced has on the time required to do another order

as yet not practiced. The part of the curve MS of MN is determined by the experiments described on pages 34 to 38 and results shown in Tables XVII. to XIX., also (1) and (2), Plate III. Points M , R , X , S and Z , and their corresponding positions on AB are determined by the experiment summed up in Table XVIII., page 37. The corresponding points on $M'N'$ and $A'B'$ of the 'error curves' (which is a schematic representation of the error curve of Plate I., and Table II. at the 104-per-minute rate), are determined by Table XIX., page 38.

A great deal of what Bergström interprets as *interference* is not that at all. The increased time a new order requires over the old practiced order is due to learning the new order, and not to resistance from the old. If there is actual interference as defined above, it is due to indisposition rather than to inability. We become a slave to a habit because we will not make the effort to free ourselves from it by a better or more desirable one.

In my later, more general discussion, I shall go more into detail as to the reason for the phenomena of these experiments. I shall take into consideration the physiological mechanism and the processes involved in the forming of associations. I shall take into consideration also a great many facts and phenomena of association observed, but not yet mentioned, which will help us to understand the physiological processes involved, and to advance a theory consistent with all the facts at hand. I shall, therefore, now proceed to a discussion and coordination of these facts, and their bearing on my theory and the results of the experiments obtained by others.

Our experimental results show, as also do Münsterberg's, that a habit associated with a given sensory stimulus or series of stimuli can continue automatically while some effect of a previous and different habit associated with the same stimulus or series of stimuli remains. And by returning to the old habit each time one becomes automatic, it takes less and less time to relearn that habit, until finally either of the two habits becomes automatic, one needing but to start the impulse in one direction or the other, and the responses continue and the adjustment is maintained just as easily as though that were the only response or adjustment ever acquired to that situation.

These results corroborate the phenomena of everyday life—social phenomena, for example; people brought up in one dis-

strict become better and better adjusted to the conditions of that district and acquire the provincialisms and the conventionalities of that district. These provincialisms are the more marked in rural districts not subject to a wide communication and the influences of the world. The young folks of such a district are taught and coerced to respond in a way consistent with the social habits and customs of that community until their reactions have become automatic. If now a young person, thus adjusted to the moral, social, religious and economic traditions of a community, leaves that community and goes to another where these conditions are different, he gets homesick. Any one who has for several years attended a boarding or dormitory school has heard a great many epithets of description, such as, *e. g.*, bashful, fresh, young, green, new, slow, etc., applied to the students of the younger class, which characterize this resistance to the new responses which an adjustment to the present environment demands.

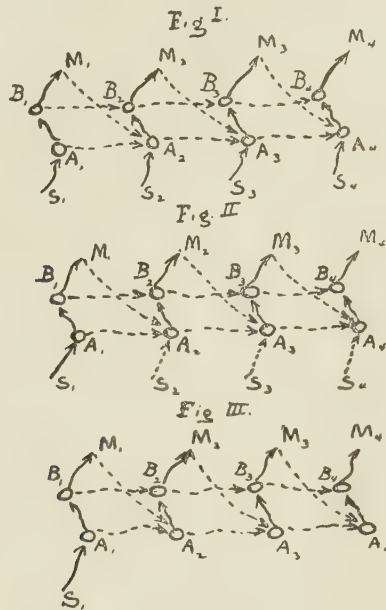
It has also often been noticed that young people who have been away from home for but a year or so (this applies especially to students) make themselves both uncomfortable and disagreeable when they come home for a vacation. They have become quite adjusted to the new situation, and when they come back they find the people uninteresting and 'slow,' and they are in turn considered as 'stuck-up,' affected, etc. One who has been away from home for a number of years and has occasionally come back to his old community for a vacation, finally does not any more attract attention, but usually enjoys his stay at home very much. These phenomena are universal and must have a physiological basis. The oftener one returns from one environment to another the less will grow the resistance. He will finally learn to conform quite easily and agreeably to either situation. The traveler who goes continually from one set of conditions to another eventually passes as easily in any one, and can make himself as agreeable to the people of that community as though he never lived in any other than their environment and knew no other than their customs, traditions and beliefs. He becomes an almost automatic conformer wherever he goes, however great the social diversities. He is at home with beg-

gars or kings, with business men or society ladies. He is a citizen of the world.

Foreigners coming to this country are easily pointed out, but after they have been here for some time they become adjusted, and pass as normal citizens. If afterward they return to the fatherland and remain there for a time and then come back, after doing this for a number of times they cannot be distinguished from ordinary citizens either here or abroad. Institutional children feel shy outside the doors of their institutional home, but after being sent out for a number of times on the streets, and to school, they become like other children. They will act like institutional children while inside their own yard, and like children of the streets while on the streets. Richard Mansfield can be Dr. Jekyll one moment and Mr. Hyde the next. With much practice it has become very easy to alternate from one to the other. It seems, therefore, that the social phenomena we see about us in ordinary everyday life are founded on the same physiological basis as those of the habits formed and broken in these experiments, and that a physiological explanation of these will also be adequate for all the social phenomena of life. The physiological explanation which I shall offer of the phenomena of our experiments can, I believe, be generalized so as to offer a solution for the phenomena of our mental life in general.

How can these phenomena be explained physiologically? Figures 1 to 3 show a graphic representation of the neural connections that are made in the forming of a habit. The formation of a habit involves two things, a connection between stimulus and response—*i. e.*, a sensori-motor connection and a sequential connection between the stimuli—or the responses, in serial order. In the case of our experiments a definite connection was gradually built up between each color and the definite response to it on the keys, and also between the colors in serial order as successive sensations, or as successive responses. The Figs. 1, 2 and 3 show schematically what physiological changes take place when a sensation, or series of sensations, is responded to voluntarily by a movement, or series of movements, and how through repetition these connections become *clinched* so that the movements follow automatically the stim-

uli. In Fig. 1, $S_1, S_2, \dots$ represent certain sense impressions which are conveyed by the proper dendrites respectively to the



In Figs. 1 to 3, $S_1, S_2, \dots$ represent the individual sense impressions coming in in serial order to the sense nuclei $A_1, A_2, \dots$ and these are respectively discharged into motor cells $B_1, B_2, \dots$ so as to bring about the voluntary movements $M_1, M_2, \dots$. Besides these sensori-motor connections there are also connections made between the motor cells $B_1, B_2, \dots$, in the order discharged, and also between the sensory cells $A_1, A_2, \dots$, in the order stimulated. There is further a third connection made between the sensation of the movement $M_1, \dots$ and the sensation from the stimulus $S_2, \dots$ which discharge $A_2, \dots$. Finally, only sensation from the movement of the previous discharge of the M cells is required to set off a discharge in the A cells, and the act continues, Fig. 3, without the sense impressions $S_2, \dots$.

sensory cells $A_1, A_2, \dots$ in the brain. These cells discharge respectively into motor cells $B_1, B_2, \dots$, and these discharging, in order, send the motor impulses, by means of their dendrites, to the muscles which produce respectively movements $M_1, M_2, \dots$. Thus, with a number of repetitions a definite sensori-motor path S, A, B, M is established, so that when S_1 is presented M_1 follows automatically in consequence. Likewise, if $S_2, S_3, \dots$ are presented, $M_2, M_3, \dots$ follow also. The oftener a sensori-motor process is repeated the more definite and

unerring become the connections, until when a sufficient number of repetitions have been made the connection becomes permanent and a habit is formed, and we respond to a given S , non-voluntarily, by a specific movement M . There is also a strong connection formed, as these experiments show, between cells that for a number of times have been stimulated or discharged together or in succession. Physiologically the law of contiguity of association might be stated as follows: Cells that have been stimulated or discharged together, when one is stimulated or discharged, the others tend to be stimulated or discharged also, and the oftener cells have thus been associated together when any one is stimulated or discharged, the greater the tendency of the simultaneous stimulation or discharge of the others.

But our experiment is concerned mainly with the law of succession, which might be stated as follows: Stimuli, or responses which have followed in serial order when one of these stimuli is presented, or one of these responses is made, the other stimuli or responses tend to be called up in their serial order. Our experiments show that the strongest connection is made between the individual stimuli and their responses. These are the sensori-motor connections. But there is also a strong connection formed between the cells that have been for a number of times in function in serial order. This connection is represented in Figs. 1, 2 and 3 by the dotted lines between the cells. The discharges of the sensory and motor cells A_1 and B_1 become connected respectively with the discharges of sensory and motor cells A_2 and B_2 which follow immediately in serial order. The oftener the process is repeated, as in the sensori-motor connections, the more permanent and definite the connections. And the persistency of this connection can only be realized when the serial order is changed. Our typewriter experiments definitely show that such sensori-sensory, or motor-motor connections are formed, and are more than half as strong as the sensori-motor connections.

There is also, apparently, a third way in which connections are formed in our mental and active life, *i. e.*, interconnections between the sensori-motor, the sensori-sensory, and the motor-motor processes. When for a number of times a series of sen-

sations, accompanied by their respective responses, follow each other in a definite serial order, the sensation of the movement of the response to each of the stimuli in the series gets associated with the sensation of the succeeding stimulus, and these two sensations together discharge the sensory cell of the second stimulus, and this discharge causes the discharge of the motor cell, habitually discharged with it, and causes the second movement. The sense impulse from this movement is again associated with the impulse of the succeeding sense impression, and so the process continues to the end of the series. To refer again to Fig. 1 as an illustration of the physiological process, when the motor cell B_1 discharges, as a result of the discharge of sensory cell A_1 , and causes movement M_1 , the sensation of that movement plus the sense impulse coming from the second sense impression S_2 discharges sensory cell A_2 , which discharges into motor cell B_2 and causes movement M_2 , the sensation of this movement again being associated with sense impulse S_3 , and so the process continues to the end of the series. The discharge of sense cell A_1 , which habitually precedes in the serial order the discharge of sense cell A_2 , changes the *tonus* of cell A_2 and renders it more irritable and susceptible to discharge. Likewise motor cell B_1 precedes in its discharge motor cell B_2 , renders it irritable, and makes it more easily discharged. The oftener a process is repeated the greater the permeability between the cells associated, and finally the usual paths become so well defined that the impulse when once started continues automatically until the act is completed, even if not reinforced by the serial sense impressions.

Learning by heart a passage of poetry illustrates the increasing permanency of connection between the cells involved in the process of learning with the successive repetitions. For some time while the learning is in progress it is necessary to have the passage before the eyes. When we have just learned to repeat by heart and for some time after, especially if we are of the visual type, we image the passage while we are repeating. We project it before our eyes and see it there. We see the position of each word on the page as we proceed. If we are of the auditory type we hear ourselves saying it as we represent it to our-

selves. The motor type has less tendency to represent it in this way than the visual and auditory.¹ Figs. 2 and 3 represent what happens physiologically. When we have just learned to repeat by heart we image the sense impressions as we respond. In Fig. 2, sensory cell A_2 is discharged in consequence of its heightened irritability, by the discharge of sense cell A_1 , which habitually precedes it, and the sense impulse, coming from the movement M_1 , resulting from the discharge of A_1 . Now when A_2 is discharged it brings to mind the external stimulus which had previously and habitually caused its irritation while the learning was in process, hence the imaging of the stimulus. If the process is sufficiently often repeated the vividness of the image as projected wanes and is finally dropped out altogether (Fig. 3). Eventually we can repeat the stanza or passage without any reference to where we learned it and to its position on the page, etc. The process becomes mechanical and needs but be started voluntarily. When started, like walking, it will go on automatically while the mind may be occupied by something else. The only stimuli necessary to keep the process in operation are the sensations of the successive movements as they follow in serial order in the process. Repeating a passage becomes as much a habit as anything else. Exactly the same physiological process is involved.

As our experiments show, we can learn to do several things, mechanically, in response to the same stimulus. At first there is great interference, but this interference is gradually reduced as the various responses are practiced. The same thing is true when we wish to modify a response or series of responses, to a series of stimuli which have become associated by repetition. I taught a four-year-old boy a comical song, which I had him sing after me until he could chant it himself. I then tried having him recite the song. This he could not do. It took quite a bit of effort to get him to recite it. Even though he could sing it without a pause or error, when required to recite it there were continual pauses and song intonations. Finally he could repeat it with all kinds of modulation. I

¹ This is an inference based on the results obtained from a number of people whom I asked the type they belong to and the method they employ in learning.

remember a certain superintendent requiring all the children in the public schools in his care to be taught to recite the patriotic songs of this country. While these songs were daily sung in the schools, it required almost as much effort to teach them as new poems. The modification of responses to stimuli is not arbitrary, but is as much dependent on physiological laws as the original learning.

In learning to respond on the typewriter to a certain definite serial order of color stimuli, respectively, by a definite serial order of reactions on the colored keys, when these reactions became automatic the subject could not *name* over the series, but he could respond them in their order on the keys in the same way he had learned them. This shows how highly specialized a process is. The memory lies in the specific response. The series can be reproduced only in the way they have been habitually reacted. This reaction cannot be transferred to the lips. When one can reproduce them in the way in which one learned them it is no guarantee that he can name the series in their order. Having learned to respond the series, however, makes it more easy to learn to repeat verbally.

The learning to respond a series takes place in the following manner: Each time we repeat the series, the sensori-sensory and motor-motor, as well as the sensori-motor, cell connections become more permanent. With every repetition the *pushing power* of each stimulus becomes greater because the resistance to its impulse becomes continually less and less, and the path better defined. At first this impulse must be reinforced by impulses, from sense-impressions of the series, coming in at certain intervals, in order to keep up the series of responses. But these reinforcing impulses can be placed farther and farther apart with the successive repetitions, until the first impulse is sufficient to set off the whole series of responses without any reinforcing sense-impulses except those produced by the impulses themselves.

In our experiments the subjects were tested to see how far they could reproduce the series of responses without seeing the stimuli. At first they could respond but a few ahead of the stimuli given, but finally, two of the subjects could reproduce the whole series without reinforcing stimuli.

We made tests, other than the interference tests already described, to determine the strength of connections between the stimuli, or between the responses in serial order. Color series A and color series C, as described on page 15, were very nearly alike, series C having colors different at but two places from series A. When series A had been practiced until no more errors were made at the 104 rate, then during the practice series C was substituted for series A without the subject knowing it. The responses came as if no change had been made. The sensori-sensory and motor-motor connections were strong enough to cause the subject to overlook or actually to see the two colors wrong. This shows that many of our illusions are due to the fact that serial associations are oftentimes strong enough to overbalance sensori-motor associations. We see what we are accustomed to see in the same situation, position or serial order. Oftentimes we can only remember a thing when the situation which usually precedes the experiencing of that thing is presented. In reproducing the series from memory we could not call up a sense impression in a series until experiencing the kinæsthetic sensation of the response to the stimulus preceding in the series. When a child learns a verse of poetry or a multiplication table, he cannot begin anywhere arbitrarily, but must begin where he usually begins. He must, if he 'gets stuck,' begin again at the beginning. If one has traveled a certain road, the second time he may be able to find it himself, but if he were called upon to tell some one else the way, he could not do it. He knows only the direction to take at certain cross-roads when he gets there. The first stages of memory consist in recognition, *i. e.*, in knowing whether the responses are the same as in the previous experience.

Other illustrations showing that memory is not an absolute thing, but closely associated with certain responses, which responses were those involved in the memorizing acts, are the following: If one were to give a written examination in spelling, for example, to a class that habitually recites orally, one might expect a much lower per cent. of rightly spelled words than if the examination had been oral. Some men who are good writers are poor speakers, and *vice versa*. Being a good

speaker is no guarantee that a man is also a good writer. He becomes good only by practicing writing. Being a good speaker makes one more apt in learning to become a good writer. One being able to spell well orally can more readily learn to spell well writing than a medium speller who can do best writing. A person who is able to produce good compositions when writing may find difficulty in thinking when writing on a typewriter. A certain young lady who had for several years been a typewriter in her father's office and who did nearly all her writing on the typewriter, found it difficult to spell when writing with a pencil. When writing essays in the university she would often lay aside her pencil to make imitative movements as if on the type-writing machine to help her recall how a word is spelled. Cases of this sort are familiar to every one.

It is a commonly accepted opinion among psychologists that there can be no sensation without response or to quote Münsterberg,¹ 'We do not know of a centripetal stimulation which does not go over into centrifugal impulses.' All our thoughts are accompanied by movements and are in turn conditioned by movements. The memory of anything gets bound up with the response, as has been already emphasized, and to reproduce a memory we need but reproduce the motor adjustments accompanying our experience of the thing remembered. Thoughts come to us when we assume their wonted responses. "If we wish to inhibit a thought we must inhibit its bodily adjustment."² When we assume the bodily attitude which habitually accompanies a certain mental state, that mental state follows. If we make a reaction which has been the response to a certain situation, that situation or stimulus is brought up in our mind. "When we say the brain thinks, it is the whole body which enters into activity."³

Stricker says that he cannot imagine a movement without by that means calling into play the actual muscular feeling, through the centrifugal impulse.⁴ The fact that the bodily adjustment

¹ 'Psychology and Life,' p. 92.

² 'Inhibition,' Breese, p. 16.

³ 'Sensation et Mouvement,' Féré, p. 25.

⁴ 'Bewegungsvorstellungen,' p. 27 ff.

even though arbitrarily made, recalls to mind the feeling and experience usually connected with that adjustment is very prettily illustrated by a two-year-old child whose associations I have studied. Last summer her father took her with him fishing, and she was taught to show how big a 'fishy' papa caught by spreading her arms. One day six months later, when for a long time she had not shown any one how big the fish was, her father had her standing on his knee, when all of a sudden she lost her balance and threw out her arms to regain it. This adjustment called to her mind her former association and she exclaimed, 'O, papa, fishy, fishy!'

Certain bodily adjustments which are responses to certain stimuli or situations, when often repeated either voluntarily or as natural responses, become habitual, and the body tends to assume those adjustments or attitudes. In this way dispositions are built up. And we hear of melancholy and jovial dispositions, etc. These habitual bodily attitudes inhibit thoughts whose bodily responses are antagonistic to the habitual bodily attitude of the disposition, and in this way our mental life is conditioned by the habitual adjustment.¹ 'All mental states are followed by bodily activity of some sort,'² and according to our view are conditioned and in a large measure determined by this activity. If the habitual adjustment is stronger than the tendency to respond in a natural way to a particular situation, the conscious effect of that situation will be inhibited or at least modified and colored by the habitual adjustment.

We become optimists or pessimists, altruists or egotists, by a selective habit. Every time we make a certain response to a certain stimulus we take a step toward forming a definite habit which is an element in our disposition. We cannot help forming automatic habits and thus definite dispositions. The problems of education are what kinds of habits we should form, what kind of a disposition we should cultivate, and hence what type of mental life we should have. The direction which our mental development shall take is determined largely by what

¹ 'Ueber den Einfluss der Gefühle auf die Vorstellungsbewegung,' Robert Saxinger, *Zeitschr. f. Psych.*, Bd. 27, Heft 1 and 2, p. 18.

² 'Psychology,' Briefer Course, James, p. 5.

bodily attitude we shall take. How we shall respond to a given stimulus depends on how we have responded, what we shall think on what we have thought, and the attitude we shall take on the attitude we have taken. What our past life has been determines in large measure what our present life and future life shall be. We cannot divide our life. Every one is conscious of this fact. A man who has been honest in his past dealings is trusted because everybody knows from experience that men generally live consistently with their past life. We become morally automatic. If the question of free will and determinism should come up here we would say that a man is free to will but he cannot choose his desires. He can choose between desires, but his past life determines what these shall be. There is a selection of desires just as there is of our mental content and of responses. Indeed, one is but another aspect of the other.

We can overcome an undesirable disposition by voluntarily assuming and holding ourselves in the bodily attitude of the disposition we wish to cultivate. The method is exactly the same as breaking up a bad habit. We cannot inhibit an undesirable disposition or habit, but we can voluntarily substitute desirable responses for undesirable ones, and thus eventually the new disposition or habit becomes automatic after a sufficient number of repetitions. Thus one habit or disposition can gain ascendancy over another only after long and patient practice of that habit or disposition voluntarily. But if the old disposition or habit is referred to several times one is very liable to lapse. There remains a residue in the old paths, and a very few impulses will make them as permeable as ever. A good illustration of this is the habitual drunkard who had voluntarily abstained until he had overcome his old drinking habit, and then by taking a few drinks was brought back again to his old disposition. Men who have not thoroughly overcome a bad habit, when they relax themselves will oftentimes fall back to the old adjustment. Conversion is not an instantaneous process, but requires a long voluntary substitution of desirable responses for those condemned. The great temptation of the devil which converts experience is the feeling of strain in holding them-

selves in adjustment antagonistic to the habitual adjustment. It is the consciousness of a tendency to relax, to let the body assume its habitual adjustment, and to let the impulses go in their usual courses, and a feeling of exertion in directing the impulses in right channels.

In the same manner attention can be explained. At first we attend voluntarily. Holding our attention to a thing is responding to that thing—adjusting ourselves to that thing. After a while that adjustment becomes habitual, and attention in that situation becomes involuntary and automatic. Our attention is where our bodily adjustment is. It is always a strain to any one to try to attend to anything adverse to the habitual bodily adjustment. And as soon as one relaxes his voluntary effort he tends to fall back into his habitual adjustment, and consequently also his thoughts and attention lapse back to the situation of that adjustment. When we listen to an interesting lecturer whom we try to follow, we find our efforts interspersed with relaxations and our body going into its habitual adjustment and our thoughts wandering.

The person of a sad disposition has certain habitual bodily adjustments, such as a drooping countenance, pouting lips, downcast eyes, drawn-in chest and a feeble gait. This disposition can be overcome by following the common-sense advice of 'bracing up.' We cannot inhibit a feeling of sadness by trying to suppress it. "If one attempts to thrust out of consciousness an idea, or an emotion, the attempt serves only to intensify it. * * * The will is successful in inhibiting mental states only when working through the motor adjustments of the body. * * * A change of bodily activity tends to bring about a change of mental states."¹ We can overcome a disposition of sadness by keeping on bracing up until that bodily adjustment becomes habitual.

Whenever we are awake we hold ourselves in a certain adjustment to our environment. That adjustment is partly determined by our habitual adjustment, *i. e.*, our disposition, and partly by the stimuli present. When one is soundly asleep he is unconscious, and to be soundly asleep or entirely uncon-

¹ *Loc. cit.*, pp. 56, 2.

scious one must be completely relaxed. Whenever we are awake we hold ourselves in a certain adjustment to our environment, and like a tightened string we respond to the changes in that environment. Holding up one's head is action, and when we are asleep we are like a broken string, we are relaxed and do not respond. One dreams only before he is thoroughly asleep, *i. e.*, before his body is completely relaxed. Dreams can easily be interpreted in terms of response. Soundly-sleeping persons cannot dream. If in our sleep we get into some bodily adjustment or make some response which is the adjustment or response to some situation or sense impression we have made in some waking state, the images or situations of the dream will be those which brought about the same adjustment in some waking state. The *cue* to past experiences seems to be in the responses. A memory of a past experience comes up, as already explained, when we get into the bodily attitude of that experience. When we get into a bodily adjustment which was the response to a stimulus in the past, that stimulus is called up in our minds and imaged.

To go back to the figures again, when M_1 is produced, the sensation of that movement irritates A_1 and A_2 and the sense-impressions which habitually stimulate these cells will be imagined. Likewise in dreams if the adjustment M_1 is produced, the sense cells A_1 and A_2 are stimulated by the sensation caused by the adjustment M_1 . In the case of sadness, etc., if one puts himself into a sad attitude, a memory of some specific sorrow will come up in his mind, a sorrow which he has experienced and to which he has responded by a sorrowful attitude. When one gets into the attitude M_1 there will be produced some specific sorrowful sight S_2 , which is due to the projection of the sense-impression which usually stimulates sense cell A_2 now irritated by the sensation coming from the movement M_1 or the attitude M_1 .

If we make a movement either by chance or in response to a stimulus, and if that movement is an element or contains an element of a movement which was made in response to a different stimulus, that stimulus is brought up in the mind. This explains quasi-thinking and mind-wanderings. If two responses

have been made together, when one of these is afterward again produced as a result of its stimulus being present, the other tends to be made also, and thus things that we have experienced together before tend to be recalled together. If we make the movement, or put ourselves into the attitude M_1 which has been the response made or the attitude taken in some past experience to S_1 , then that past experience is brought up in our minds.

On this basis a great many of the mental phenomena, usually puzzling to the psychologist, can be explained, as, *e. g.*, the communication between minds when a number of persons are trying to entertain one another by telling stories; the stories one tells suggest stories to others in the following way: We follow the speaker with a continual response. This is shown by the fact that we become hoarse by listening to an interesting lecturer.¹ We are made to laugh or cry, to feel sadness, sympathy, hatred, revenge, etc. These are responses. If some of the responses which we are caused to make by the story, that is being told, are responses we made on a previous occasion when a different story was being told, that story is called up in our mind. A second story-teller oftentimes begins by 'That reminds me,' etc., and his story in a similar manner suggests stories to other members of the company. The cue to our past experiences lies largely in our responses. Memories of past experiences are brought up by our reactions. Our mental life is just as varied as our responses. We make infinitely more, and more varied, responses than the lower animals by means of gesture and our vocal organs, and this accounts for the difference in our mental life. Merely seeing a thing does not give us a knowledge or memory of it; we learn to discriminate only what we are called upon to react. Differences are forced upon us through differences of reaction we make. By means of language and gesture we are enabled to make more delicate discriminations than the lower animals. The animal's responses are confined to narrow limits. We are taught to make delicate responses. We are taught to *describe* a thing. We are taught to read and write and in this way we are obliged to make fine discriminations. We are taught arbitrary responses to sense

¹ 'Inhibition,' Breese, p. 16.

impressions, and these responses afterward become the cue to the object for which they are the reactions.

The child is taught to make certain conventional responses to the things he comes in contact with. For example, he sees a certain animal; he is taught to respond to it in a definite way, *i. e.*, by the vocal response *cat*. Likewise he is taught similar responses to all other animals and things. These responses become definitely associated by repetition, respectively, with these things. Through education, through the bringing together of experience by means of language, things become associated which without language could never be experienced together or be associated. Language makes a community of responses possible. All have been taught to make the same responses to the same sense impressions. Language is the most conventional thing the human race is in possession of. It is the means by which we can reexperience the experiences of the past. By reading a book—a history or drama—we can experience the experiences of that drama. As we pronounce the words, which words are respectively the responses to certain sense-impressions we have already made, that pronunciation calls up images of the objects of which these are the names. And in this way one makes an indefinite number of associations otherwise impossible. We discern things only in so far as we respond to them. The animal makes a gross response to a general situation, whereas we learn to discriminate very sharply. We learn to describe, to notice details, but without language and gesture we could not do this.

Now if it were not for language, this artificial way of responding to our world of things by giving them names, our mental content, and our associations would be comparatively meager. By means of language we are enabled to associate experiences which are far apart in time and space by responding them together or in succession. If we make any response, either to a stimulus present or as a result of a response to some stimulus in the previous moment, there is a tendency for that response to be accompanied by other responses which accompanied it before, and to be succeeded by responses which followed it at some former time, the physiological process involved

being precisely the same as that already explained, page 49, in case of our experiment. In this way the mental content at any one moment and the trend of thought can be accounted for and explained.

A great deal of our past experience is bound up with our speech organs. When we think, our vocal organs are slightly innervated. Children cannot think without innervating their vocal organs considerably. This vocal innervation is greatly reduced in the adult when he studies, but that it is not entirely absent is shown by introspection. We cannot think except in terms of responses, *i. e.*, the words by which we represent to ourselves the things to be thought about. Our thought is inhibited when we suppress the motor responses of the speech organs. Smith¹ found that counting had no effect on the memory for series whose motor adjustments were made by parts of the body not involved in the counting process, whereas it distracted the memory greatly for nonsense syllables whose motor adjustments involved the speech organs. The results of W. G. Smith and Cohn, also reviewed at the beginning of this article, likewise corroborate the theory herein advanced.

We have made experiments showing that very little can be remembered of what transpired in our presence when the body was completely relaxed. The experiment consisted in reading a passage to the subject while lying on a couch thoroughly relaxed, and then seeing how much of the passage he could reproduce. Sometimes not a thought in the passage could be remembered. Introspections received from a score of professors and students of psychology show that one cannot think *a, b, c* . . . rapidly and at the same time repeat *1, 1, 1, . . .*, nor can one think alternately lower and upper *do* without innervating, or a tendency to innervate the speech organs.

An experiment which I made last year,² in which I learned to move my ears, shows a striking illustration of how a response becomes the symbol of a sense impression or a situation. I learned to move my ears in the psychological laboratory of Michi-

¹ See my review of his work, page 11.

² 'Development of Voluntary Control,' PSYCHOL. REV., Vol. VIII., No. 5, Sept., 1901.

gan University, and now whenever I move them a picture of the laboratory is brought up in my mind such as I saw when I learned to make the movements. This again shows that if we put ourselves into a bodily adjustment which was a previous response to some particular situation, that situation tends to be called up and imaged. Any response, whether of the vocal organs, of gesture or of the viscera, which has been a reaction to some stimulus, when now made either arbitrarily or by chance is likely to bring up that stimulus in the mind. If we affect a bodily attitude which usually accompanies sorrowful events we can bring about a sorrowful feeling, and some specific sorrowful event in one's past life is usually called up. Specific reactions tend to be accompanied by specific memories; this is true, at least of the vocal reactions. The body seems to be a machine for making specific reactions to specific stimuli, and when a specific reaction is arbitrarily made it calls up the stimulus with which it was formerly associated. When a reaction to a stimulus present has an element in common with a reaction formerly made to a different stimulus, that reaction tends to call up the former stimulus.

We are becoming more and more convinced of the importance of the motor element as a factor in our mental life. From the standpoint of the function of this element we have already discussed association, discrimination, memory, sleep and dreams, habit, disposition, interest and attention, mental content and the trend of thought. On the same basis reasoning, imagination and the other mental processes could be accounted for.

The question now comes up whether special training gives general ability, and if so what is the physiological explanation for the same? One holding that the body is a machine for making specific reactions to specific sense impressions or situations would at first thought probably say that training or education consists in a number of specific abilities and that there is no such a thing as general training, and if he held such a theory would doubtless be accused of inconsistency. But if he considers the physiological processes involved he is more ready to modify his views. Admitting that education consists largely in learning to make certain responses to certain stimuli and inhibit-

ing others, thus forming desirable habits, we must also admit that learning to make these specific reactions also helps us to locate ourselves in our physical world. As soon as we grasp the significance of the motor element we see that any bit of special training also helps us to receive training in general. Any training helps us to find ourselves. It gives us a method of orientation which leaves us in our reactions not entirely to the mercy of chance even in unfamiliar situations. The experience which we get from special training gives us a general power to meet an entirely new situation with a more favorable response than had we not had this special training. We learn to react to a certain sense impression in a way that brings about the desired end through trial and error. We have learned in a similar manner to respond to a great many sense impressions or situations in such a way as to bring about pleasure or avoid pain. To a new situation, therefore, we react by a discriminative reaction and are more likely to hit upon a favorable response than without this special training.

To be more concrete, suppose one is called upon to imitate a sound the like of which he never heard before. He will be aided by his general experience in imitating other sounds, and that general experience helps him to direct the imitative impulse. It helps him, *e. g.*, to send the impulse to the vocal organs, if nothing more, instead of to the hand or foot, which would be imaginable if he had never had experience either in imitating sounds or moving his hand or foot.

Let Fig. 4 represent the brain and its motor connections, *N* representing the center of coordinations, and *A*, *B*, *C*, . . . the general motor tracts. *A* represents the motor tracts to the lower limbs, *B* to the arms, and *C* to the speech organs, etc. Now, as in the case supposed above, in which special training gives us a method of orientation, it helps us to express ourselves in the gratifying direction, *i. e.*, helps us to send the impulse into the channel *C*, that innervating the vocal organs, instead of channels *A* or *B*, which would result, respectively, in a movement of the leg or a flirt of the hand. Our general experience, the experience resulting from special reactions, helps us, in our attempt to imitate the sound stimulus, to react in the direction of

C rather than in that of *A* or *B*. If we could imagine a being with imitative impulses, but with no experience of the results of definite responses to definite stimuli, and with no sensori-motor associations, then the chances of the imitative impulses going in the direction of *A*, *B*, etc., would be evenly distributed. Special training, therefore, gives us general ability in that it

Fig. IV.



Fig. 4 is a schematic representation of the brain and efferent nerves. Branches *A*, *B*, *C*, . . . are the motor nerves supplying the different parts of the body. *C* supplies the vocal organs and 1, 2, 3, . . . represent branches of *C*, which, when innervated, produce respectively different sounds. The figure will be discussed in the text.

gives us a method of orientation, and thus we are benefited in a general way by our past experience.

Our sixth experiment, described on page 24, the results of which are summed up in Table VIII., page 25, seems to show that special practice gives general ability, as well as special. The first three subjects were new, and served only in this particular experiment, while the fourth subject, Sm., served in all the experiments. It might be argued that the practice effect here is due to getting adjusted to the typewriter in general, as, *e. g.*, getting accustomed to the stroke of the keys, learning to expend just about the right amount of energy, learning or getting accustomed to seeing the stimuli. We are willing to admit

that some of this practice effect is due to these factors, but why should Sm., who had long since gotten adjusted to all those conditions by many previous practices, also show almost as much practice as the others? This is difficult to explain unless we admit the point at issue. Others of our experiments lead to the same conclusion. The results of these will be discussed later.

The *a, b, c* tests described on pages 27-28, Table XI., p. 28, might throw some further light on the theories already advanced, concerning the physiological process of association. We see by the table that in the *a b c* series, *i. e.*, repeating alphabet forward, there was very little time gained by practice. This is due to the fact of former practice, whereby the sensori-motor and serial connections were definitely established. When this serial association was interrupted by placing a letter between each of the letters in the series (*an, bn, cn*, etc.) there was much interference at first, but adjustment was very rapid. This is shown by the curve, Plate II. When the series was repeated backward (*z, y, x, . . .*) the curve shows the same rate of rapid adjustment, as also does the curve when the backward series is intercepted by a letter (*zn, yn, xn, . . .*). When the forward practice was begun the subjects had already had considerable practice in repeating the alphabet, hence the serial coordinations were pretty well made. In all the alphabet experiments the sensori-motor coordinations were thoroughly made by previous training; the practice consisted in establishing the different serial orders. When the letters were intercepted by *n* there was great interference, the reason for which can be understood when the physiological processes involved are considered. Using once again Fig. 1, if cell A_2 is discharged either by a sense impression S_2 (the picture of a letter), or by a sense impulse coming from the movement M_1 (feeling oneself saying the letter preceding), or by both, in our case by the latter, *i. e.*, the kinæsthetic sensation only, this discharge of A_2 affects the tonus of A_3 , and the discharge of B_2 which results from A_2 affects the tonus of B_3 which usually follow in their discharges in serial order the discharges of A_2 and B_2 respectively. The kinæsthetic sense impulse from the movement M_2

coming back to A_3 , if not inhibited, is sufficient to discharge A_3 , which would again render A_4 irritable, discharge B_3 , irritate B_4 , produce movement M_3 , and impulse from M_3 , discharge A_4 , and thus keep the process going automatically to the end of the series, as they are habitually responded. But where a letter is to be intercepted, when A_2 is discharged into B_2 , the processes as associated would now discharge A_3 and B_3 , but this discharge must be inhibited by voluntarily discharging A_n and B_n , then A_3 and B_3 , A_n , B_n and A_4 , B_4 , etc. Every time this new serial process is repeated, when A_2 and B_2 are discharged, the irritability of A_n and B_n becomes progressively greater, while that of A_3 and B_3 less, until finally the new serial progress becomes automatic.

Now, as I have already shown, there is probably not such a thing as *interference*. When we practice the $sn, bn, cn, \dots$ series until we have acquired great speed, and then refer again to the $a, b, c, \dots$ series, we find that we can repeat as rapidly as ever. It is also shown that we can learn the $an, bn, \dots$ series more rapidly after having learned the a, b, c order than otherwise. Learning the alphabet in any order helps to learn it in any other order.

The child in imitating anything, *e. g.*, a sound, has in a general way connected sounds with their reproduction by himself, and he has learned in what direction to send the impulse in order that he may reproduce a sound. Referring for a final time to Fig. 4, suppose the sound to be represented is produced by sending the impulse to δ , but he sends the impulse to γ , and is dissatisfied with it, tries again, and now produces ι , still farther away, which he will recognize. He tries again and may continue until he gets a gratifying response. In this way he learns that certain vocal innervations produce certain sounds. He learns to find himself as much by his unsuccessful reactions as by his successful ones. He learns the conditions under which certain responses are produced and he can arbitrarily make any response he has ever made, and these past reactions have given him a method of orientation. For example, if a person has learned to sing over the scale of notes up to Si and has never produced that note, he is more likely to hit upon it in an attempt

to imitate it than if he had never produced the series. He gets control of his vocal apparatus, and is able to produce sounds he has never before produced by the method of experience. Having once made a certain response is no absolute guarantee that one can reproduce it voluntarily; the oftener he repeats, however, the more command he will have of that response.

This is shown by the experiment of throwing shot into a cup, Table XIV., p. 30. We make certain movements, attempts to accomplish some end; in this case to put the shot in the cup. Our first attempt may be far of the mark, or it may be successful. In repeated attempts we are sometimes successful and sometimes not. But we gradually eliminate the unsuccessful responses, and if we practice long enough our results will be unerring, and there will be no more wrong responses. In learning to do things we ordinarily learn to do them only so well that we can get along. Bryan and Harter have found this to be the case with telegraphy. This they called the first plateau of proficiency, but an expert must go beyond this and by extra effort ascend to a higher plateau of proficiency. This is what distinguishes a Cinquevalli from an ordinary juggler. He makes no more wrong reactions, but hits his mark every time. A practice curve represents in a certain number of trials a certain distribution around the mark aimed at. This distribution is more or less scattered. With increased practice the distribution of hits becomes more and more concentrated about the mark until finally, if the practice is long enough continued, only comparatively few efforts will fail of their intended goal.

The way, therefore, that all these phenomena of practice must be interpreted from a physiological standpoint is in terms of selection. The outgoing impulse is arbitrary just in so far as it is not determined by experience. The coordination of the results of our effort and the end sought to be attained by that effort give us a working basis toward adjustment by means of selection. Better adjustment is due to the elimination of unsuccessful reactions which were made in pursuit of some end. I believe that a right interpretation of our facts as schematized

in the last two figures, Plate III., would be to say that there are two factors involved in practice, first, as just stated, a better adjustment through a selection from all the reactions of the most gratifying, the rapidity of this selection, in one case, being represented by the curve A' , B' of the last figure, Plate III.; secondly, the more general factor, that of experience. Everything in the world of experiences is related because all is bound up with the reactions of one experiencing subject. We are put into our world ignorant of its laws. We find ourselves through trial and error. The wrong reactions of one situation oftentimes afford us a means of adjustment to another situation. We *find* ourselves in our world just as much through error as through gratifying reactions. We are rationally adjusted to our environment just because a whole past has made wrong reactions. We find the law by means of transgression. The past has therefore paid the price for our freedom. Experience rationalized, experience largely made up of errors, gives us a method of orientation. This method gives us insight, power to grasp the situation to which we are called upon to respond; our reactions are at once discriminative. The animal, just because it is reflexly adjusted to its environment, does not have this discriminative reaction, and hence cannot have reflective experience. It cannot survive a change of conditions. The quantity of insight we get to grasp the situation is represented in our diagram by curve M' , C' . The more bearing one thing, that we have practiced, has on another, which we are called upon to react, the better we are prepared to make a favorable response, and if the two situations were exactly alike M' , C' and A , B would coincide, *i. e.*, any amount of adjustment in one would give a similar amount in the other. We reason in a situation. We compare this situation with a situation we have experienced. We note the likes and differences and draw inferences. And in this way special training, learning to do particular things, gives us general ability and a method of deportment. Training implies not only the sum total of special abilities practiced, but it also implies a working method whereby we meet the conditions of our environment rationally and in such a way as to bring about the end sought.

VITA.

The author of this dissertation, Joseph Hershey Bair, was born June 21, 1875, at Hall, Pennsylvania. He received his early education in the public schools of the place of his birth, and in the academy at Rossville, Pa., which he attended for three successive terms. He taught a district school two years and then entered the Central State Normal School at Lock Haven, Pa., 1894, and was graduated in 1895. In 1896 he was principal of a ward school in Middletown, Pa. He attended Lafayette and Grove City Colleges '97, '98, '99, and received the Ph.B. degree from the latter at the end of the summer term of '99. He then entered the University of Michigan as a student of psychology, philosophy, sociology, and economics, and received the Ph.B. degree in 1900 and the A.M. in 1901. The results of his research work in psychology at Michigan, on "The Development of Voluntary Control," were published in the *PSYCHOLOGICAL REVIEW*, September, 1901. He entered Columbia University October, 1901, as a scholar in psychology, and pursued studies in psychology, anthropology, and sociology. It was here that the experiments described in this thesis were made. The author was assistant in psychology in the Columbia University Summer School of 1902 and is now assistant in anthropology.

